PB85-160406

Liquid Waste Composting

(U.S.) National Park Service, Washington, DC

Prepared for

Environmental Protection Agency, Cincinnati, OH

Jan 85

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-160406

EPA/600/2-85/005
January 1985

LIQUID WASTE COMPOSTING

by

James C. Patterson
John R. Short
National Park Service
U.S. Department of the Interior
Washington, D.C. 20242

EPA-78-D-X0298

Project Officer

Robert P.G. Bowker
Office of Research and Development
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

This study was conducted
in cooperation with
U.S. Department of the Interior
Washington, D.C. 20242

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
Cincinnati, Ohio 45268

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

SECTION 1

INTRODUCTION

Concentrated liquid human waste materials have been traditionally difficult to adequately treat. This problem is more acute in rural areas, recreation sites, back-country locations and other areas where conventional facilities to adequately treat such wastes are often too costly to construct and operate. In these rural areas, alternative waste treatment systems are receiving increased visibility. Technological advances have produced environmentally acceptable methods of treating these materials with relatively low capital investment and operational costs.

Composting technology offers a potentially attractive alternative for handling these liquid wastes. Further demonstration may be necessary to accurately predict costs, operational needs, and materials handling requirements, and to resolve issues involving product quality, use, and environmental safety. The composting process offers wide flexibility with regard to regional, climatic, and waste generation variability; it is a system that is widely adaptable to varying organic waste materials and treatment needs; and the final product has value as a soil amendment.

The National Park Service, Chesapeake and Ohio Canal National Historical Park (C&O Canal) was faced with a serious waste disposal problem in 1975. Several years prior to 1975, pit toilets were replaced with sanitary tank type or portable toilets from which raw wastes had to be pumped and disposed of within municipal treatment facilities. For a period of time, waste disposal at local municipal plants was permitted; however, without warning, the C&O Canal was refused further disposal privileges. A thorough investigation of alternatives led to the selection of the aerated static pile composting system developed by the U.S.D.A. as being the most workable alternative.

A major unknown existed. Could liquid waste material, at that time estimated to be greater than 95 percent liquid, be successfully composted? In 1976, a pilot project was initiated to evaluate the feasibility of composting sanitary toilet waste. Later, the scope was expanded to investigate composting of a blend of septic tank waste (septage) and sanitary toilet waste. This also proved successful.

Gradually, over the 2 year period, considerable success was realized. The system developed by Beltsville was substantially modified to effectively compost these wastes.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/2-85/005	2.
3. RECIPIENT'S ACCESSION NO. PB85 160406/AS	
4. TITLE AND SUBTITLE LIQUID WASTE COMPOSTING	5. REPORT DATE January 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) James C. Patterson & John R. Short	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS National Park Service Ecological Services Lab U.S. Dept. of Interior Washington, D.C. 20242	10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. EPA-78-D-X0298
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268	13. TYPE OF REPORT AND PERIOD COVERED Final 7/78 - 7/79 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: Robert P.G. Bowker
Present Contact: Donald S. Brown (513) 684-7630

16. ABSTRACT

This research project was conducted at the Chesapeake and Ohio Canal National Historical Park to examine the feasibility of adapting and using the sludge composting technique to compost liquid waste collected in National Parks. This study evaluated the composting of two problematic liquid raw wastes--sanitary toilet pumpings and septic tank pumpings (septage). Effectiveness of the process was characterized by measuring indicator organism destruction, nutrient transformations, heavy metal content, and temperature and oxygen variation. Effective destruction of pathogenic microorganisms was achieved by temperatures in excess of 55° obtained within the composting pile.

The system was costly on a unit volume basis, but costs were reasonable when the value of the compost was considered. The process provided thorough waste treatment without costly equipment and specialized construction.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 100
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

INSTRUCTIONS

1. **REPORT NUMBER**
   Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
   Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
   Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
   Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approval, date of preparation, etc.)*.

6. **PERFORMING ORGANIZATION CODE**
   Leave blank.

7. **AUTHOR(S)**
   Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
   Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
   Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
    Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
    Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
    Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
    Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
    Leave blank.

15. **SUPPLEMENTARY NOTES**
    Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
    Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
    (a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

    (b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

    (c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
    Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. **SECURITY CLASSIFICATION**
    DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
    Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
    Insert the price set by the National Technical Information Service or the Government Printing Office, if known.

DISCLAIMER

"Although the information described in this article has been funded wholly or in part by the United States Environmental Protection Agency through Interagency Agreement number EPA 78-D-X0298 with National Park Service, it has not been subjected to the Agency's required peer and administrative review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred."

FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report documents an investigation of composting of liquid wastes utilizing a modification of the static aerated pile technique developed by the USDA in Beltsville for stabilizing dewatered sewage sludge. Results of a one year pilot study indicated that the process is capable of producing a stabililized compost product when appropriate ratios of liquid waste and organic bulking agents are achieved prior to initiation of the composting process. Liquid wastes used for this investigation were derived from the pumping of portable toilets and septic tanks.

Francis T. Mayo, Director
Water Engineering Research Laboratory

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

ABSTRACT

Low density population centers, backcountry sites, areas with poor soils, or facilities that produce concentrated raw human wastes are confronted with serious problems in treating and disposing of wastes derived from septic tanks, holding tanks, and recreational toilet facilities. Alternatives for treatment are few: spread the waste on marginal or agricultural lands; dispose of wastes into existing treatment facilities if permitted or construct specific facilities for adequate waste treatment prior to disposal.

Aerated static pile composting, as developed by the United States Department of Agriculture (USDA) - Science and Education Administration at Beltsville, Maryland, provided an alternative for treatment of dewatered sewage sludge. In 1975, the National Park Service began to examine the feasibility of adopting this composting technique to treat liquid sanitary toilet waste collected along the Chesapeake and Ohio Canal National Historical Park. Owing to low volumes of waste materials, it appeared that this system would be economical and would, if it proved functional, provide the park system with a fine soil conditioner as an end product.

After two years of National Park Service (NPS) application, the Environmental Protection Agency (EPA) provided research funding in 1978 to evaluate the feasibility of composting septage and sanitary toilet waste.

Under this agreement with EPA, effectiveness of the process was characterized by measuring indicator organism destruction, nutrient transformations, heavy metal content, and temperature, oxygen, and moisture variation. Indicator organisms and pathogens assayed included coliform, fecal coliform, and Salmonella sp. Nutrients analyzed included total Kjeldahl nitrogen (TKN), nitrate and nitrite nitrogen (NO_3 and NO_2), ammonia nitrogen (NH_4), total phosphorus (P), total potassium (K), pH, and soluble salts. Heavy metal analyses included cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn). Data on temperature and oxygen levels in the pile were collected daily during operation of the facility.

Results of this study indicate that the static pile composting technique is a viable alternative for treatment of raw concentrated human waste. Effective destruction of pathogenic microorgansms is achieved by the high temperatures (well in excess of 55° C) obtained within the composting pile. Sanitary toilet compost contained about 1.1% TKN, 0.3% P, and 0.3% K. Septage compost contained about 0.7% TKN, 0.2% P, and 0.2% K. Heavy metals analyzed were generally low because of the nature of the waste materials treated. Bulking agent requirements were significant for the raw waste, which had a total solids content of 2-3% by weight. Approximate volumetric requirements for the total compost pile per 3,785 ℓ (1,000 gallons) of waste were:

BEGIN LAST LINE OF TEXT HERE
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-2I7 (Cin.) (4-76)

mattress - 5.4 cu m woodchips; absorbant organics - 7.4 cu m woodchips, 7.4 cu m sawdust, 3.2 cu m compost; and insulation blanket 7.7 - 15.3 cu m compost.

This report was submitted in fulfillment of Interagency Agreement EPA-78-D-X0298 by the Ecological Services Laboratory, National Capital Region, National Park Service. This report covers the period of July 12, 1979.

CONTENTS

Disclaimer..... ii
Foreward..... iii
Abstract..... iv
Contents..... vi
Figures..... viii
Tables..... x
Acknowledgements..... xiii

1. Introduction..... 1

2. Conclusions..... 3

3. Literature Review..... 4
   Composting of Sewage Sludge..... 4
      Results of Beltsville Research..... 4
   Current Liquid Waste Composting Efforts..... 5
      Lebo Process..... 5
      National Park Service..... 7
      Rehoboth, MA..... 7
      U.S. Forest Service..... 10

4. Materials and Methods..... 11
   Site Description..... 11
   Acquisition of the Waste..... 12
   Description of Composting Operation..... 14
   Temperature and Oxygen Monitoring..... 16
   Sampling Procedure..... 16

5. Results and Discussion..... 37
   Sanitary Toilet Waste Composting..... 37
      Bulking Materials..... 37
      Characterization of Untreated Sanitary Toilet Waste..... 37
      Characterization of Sanitary Toilet Waste Composting..... 40
   Septage Composting..... 56
      Bulking Materials..... 56
      Characterization of Septage..... 56
      Characterization of Septage Composting..... 59

CONTENTS (Continued)

6. Economic Analysis..... 74
Capital Cost..... 74
Land..... 74
Site Development..... 74
Equipment Purchase..... 76
Labor Costs..... 76
Materials and Utilities Costs..... 76
Organic Bulking Materials..... 76
Miscellaneous Supplies..... 79
Rental Equipment..... 79
Utility Charges..... 79
Administrative Costs..... 79
Summary Costs..... 79
Product Values..... 81

7. References..... 83

FIGURES

Number		Page
1	C&O Canal Compost Site - Final Layout	13
2	Static Pile Composting System - Air Movement	15
3	Static Pile Composting System - Pile Composition	17
4	Static Pile Composting System - Sampling Locations	18
5	Static Pile Composting System - Temperature and Oxygen - Monitoring Locations	20
6	Temperature in Sanitary Compost Pile vs. Time - Location 1 - Depth 30 cm	21
7	Temperature in Sanitary Compost Pile vs. Time - Location 1 - Depth 90 cm	22
8	Temperature in Sanitary Compost Pile vs. Time - Location 2 - Depth 30 cm	23
9	Temperature in Sanitary Compost Pile vs. Time - Location 2 - Depth 90 cm	24
10	Temperature in Sanitary Compost Pile vs. Time - Location 3 - Depth 30 cm	25
11	Temperature in Sanitary Compost Pile vs. Time - Location 3 - Depth 90 cm	26
12	Temperature in Sanitary Compost Pile vs. Time - Location 4 - Depth 30 cm	27
13	Temperature in Sanitary Compost Pile vs. Time - Location 4 - Depth 90 cm	28
14	Temperature in Septage Compost Pile vs. Time - Location 1 - Depth 30 cm	29

FIGURES (Continued)

Number		Page
15	Temperature in Septage Compost Pile vs. Time - Location 1 - Depth 90 cm	30
16	Temperature in Septage Compost Pile vs. Time - Location 2 - Depth 30 cm	31
17	Temperature in Septage Compost Pile vs. Time - Location 2 - Depth 90 cm	32
18	Temperature in Septage Compost Pile vs. Time - Location 3 - Depth 30 cm	33
19	Temperature in Septage Compost Pile vs. Time - Location 3 - Depth 90 cm	34
20	Temperature in Septage Compost Pile vs. Time - Location 4 - Depth 30 cm	35
21	Temperature in Septage Compost Pile vs. Time - Location 4 - Depth 90 cm	36

TABLES

Number		Page
1	Composition of Septage & Sludge Composts	6
2	Microbe Content of Composts	8
3	Materials Used in Construction of Pilot Compost Piles, Rehoboth, MA	9
4	Quantities of Bulking Materials Used for Composting of Sanitary Toilet Waste	38
5	Sanitary Toilet Waste Characterization	39
6	Sanitary Toilet Waste - Total Coliform Bacteria Alteration With Composting Time	41
7	Sanitary Toilet Waste - Fecal Coliform Bacteria Alteration With Composting Time	42
8	Sanitary Toilet Waste - Total Solids Alteration with Composting Time	43
9	Sanitary Toilet Waste - Total Volatile Solids Alteration With Composting Time	44
10	Sanitary Toilet Waste - pH Alteration with Composting Time	45
11	Sanitary Toilet Waste - Soluble Salts Alteration With Composting Time	46
12	Sanitary Toilet Waste - Total Phosphorus Alteration With Composting Time	47
13	Sanitary Toilet Waste - Total Potassium Alteration with Composting Time	48
14	Sanitary Toilet Waste - Total Kjeldahl Nitrogen Alteration with Composting time	50
15	Sanitary Toilet Waste - Nitrate and Nitrite Nitrogen Alteration with Composting Time	51

TABLES (Continued)

Number		Page
16	Sanitary Toilet Waste - Ammonium Alteration with Composting Time	52
17	Sanitary Toilet Waste - Heavy Metal Characteristics of Raw Waste and Compost	53
18	Bulking Materials Used for Composting Septage	57
19	Septage Characterization	58
20	Septage - Total Coliform Bacteria Alteration with Composting Time	60
21	Septage - Fecal Coliform Bacteria Alteration with Composting Time	61
22	Septage - Total Solids Alteration with Composting Time	62
23	Septage - Total Volatile Solids Alteration with Composting Time	63
24	Septage - pH Alteration with Composting Time	64
25	Septage - Soluble Salts Alteration with Composting Time	65
26	Septage - Total Phosphorus Alteration with Composting Time	66
27	Septage - Total Potassium Alteration with Composting Time	67
28	Septage - Total Kjeldahl Nitrogen Alteration with Composting Time	68
29	Septage - Nitrate and Nitrite Nitrogen Alteration with Composting Time	70
30	Septage - Ammonium Alteration with Composting Time	71

TABLES (Continued)

Number		Page
31	Septage - Heavy Metal Characteristics of Raw Waste and Compost	72
32	Capital Costs of Composting Operation	75
33	Annual Labor Costs of Compost Operation	77
34	Annual Materials and Utility Costs for Compost Operation	78
35	Summary of Annual Costs of Composting Liquid Wastes	80
36	Product Value of Compost	82

ACKNOWLEDGEMENTS

As with most research projects, management and support are critical to the success of the project, particularly when dealing with waste treatment systems. Therefore, the authors are grateful to the Chesapeake and Ohio Canal National Historical Park Staff for their highly significant support. The efforts of William Failor, Dale B. Sipes, George Hicks, Richard Marshall, Robert Crowl, and Henry Burhman are most appreciated.

The staff of the Biological Waste Management and Nitrogen Laboratory, U.S. Department of Agriculture and their continued support and suggestions throughout previous years of National Park Service composting activities are most gratefully acknowledged.

Ecological Services Lab staff of the National Park Service is acknowledged, in particular Dr. Richard S. Hammerschlag, Carol Sue Rodgers, and Bruce Riggle for their direct input and assistance.

The U.S. Environmental Protection Agency in Cincinnati and Robert P. G. Bowker for his aid in developing the research project and assistance in report preparation are gratefully acknowledged.

To more thoroughly evaluate the adaptation of the aerated static pile composting system for treating liquid wastes, the U.S. Environmental Protection Agency provided research funds to the National Park Service in 1978.

This report presents findings generated by that research project which evaluated composting of two very problematic liquid raw waste materials- sanitary toilet pumpings and septic tank pumpings (septage).

This cooperative research project between the National Park Service (NPS) and the Environmental Protection Agency (EPA) was performed under Interagency Agreement No. EPA-78-D-X0298.

SECTION 2

CONCLUSIONS

Concentrated liquid waste products are difficult materials to adequately treat. The aerated static pile composting system as developed by the U.S. Department of Agriculture at Beltsville and modified by the U.S. Department of Interior, National Park Service, has proven to be an adequate treatment alternative for septage and sanitary toilet pumpings. Within a 3 week period, the waste-organic mixture is transformed into a composted material, which with a short stockpiling or curing period becomes a valuable organic soil amendment.

The system has the following features: 1) little capital expenditure is required when compared to traditional mechanical systems; 2) no full time on-site personnel are required; 3) a minimum of equipment is necessary; 4) the process produces a high degree of waste treatment with little or no release of environmental contaminants; 5) the user is provided with a highly flexible and efficient waste recycling alternative which is easily adapted to remote sites, different climatic zones, differing waste loading needs, and different organic wastes; 6) wastes can be treated as they accumulate, or stored until such time as treatment is necessary; 7) the end product contains low levels of bacterial organisms; 8) its compost is a low analysis fertilizer containing some micronutrients; and, 9) its compost is an excellent organic soil amendment which has many uses, especially on non-food chain crops and disturbed soil areas.

SECTION 3

LITERATURE REVIEW

COMPOSTING OF SEWAGE SLUDGE

Composting technology had its origin centuries ago. However, recent advances have generated renewed interest in this old form of waste recycling. The Science and Education Administration of the U.S. Department of Agriculture (USDA) at Beltsville, Maryland, has been experimenting with waste recycling technology since the early 1970's. Their first attempts at composting involved the use of the windrow system which was a highly mechanized, capital intensive composting method. That approach was of particular value to municipalities which required the handling of large quantities of sewage sludge on a daily basis. Land requirements and capital investment, however, may be significant for this type of operation.

Since that time, U.S.D.A. has refined the basic geometry of the windrow system and developed the aerated static pile composting system. Using this approach, waste-organic mixtures are blended and piled in a static mode, and utilizing the forced aeration technique, the active composting cycle is initiated. Frequent handling or mixing operations are reduced to the setup and teardown activities. Active composting occurs during the first 3 weeks, after which time the compost pile may be dismantled and placed in a stockpile for additional curing prior to utilization.

Results of Beltsville Research

Static pile composting investigated at Beltsville has proven to be a technologically and economically feasible method for stabilizing dewatered municipal sewage sludge, the product of which is valued as a soil conditioner (6, 19).

The static pile composting technique is becoming a widely used alternative for treatment of dewatered sewage sludge. Most dewatered sludges range from 15 to 25 percent solids content and are amendable to the technique. Composting functions equally well over wide ranging climatic conditions (9).

Composting dewatered sewage sludge achieves substantial reduction in concentrations of indicator organisms (11). The resulting compost may be considered a low-analysis fertilizer (N:P:K = 1.6:1.0:0.16), the greatest attribute of which is its value as a soil conditioner. Amending existing soils with this compost can favorably influence the moisture retention capacity, soil structure, aeration porosity, water permeability, cation exchange capacity, and pH (9, 23). Beltsville compost has been used extensively in

Washington, D.C. as a soil amendment for highly disturbed urban soils. One example has been its use in building the soils of Constitution Gardens for the Bicentennial year (21).

CURRENT LIQUID WASTE COMPOSTING EFFORTS

The Lebo Process

The first publicized implementation of the composting process for treatment of septic tank pumpings began in South Tacoma, WA. in January, 1974. A pilot plant was constructed to demonstrate the technical and economic feasibility of the Lebo Process for composting septic tank waste. As a result of the pilot project, full scale facilities were constructed in Bremerton and Chehalis, WA. Operation of the South Tacoma pilot facility was terminated in June of 1976; the Bremerton, WA. plant operation terminated shortly thereafter. The Chehalis, WA. facility has been in continuous operation since May, 1977 (27, 28).

Although the design and operation of the plants differ slightly, the basic process is as follows. Pumper truck contents are transferred to a large receiving tank and then the septage flows into the patented conical Lebo aerator. Compressed air is forced into the bottom, resulting in vigorous aeration through a swirling helical motion. The purpose of the violent aeration process is to oxidize or strip odorous gases and to break up large waste particles which might inhibit oxygen transfer during the composting process. A discharge valve is then opened, allowing the pressure to force the aerated septage through a U-tube and fire hose. It is then sprayed onto a bed of sawdust or wood strippings formed with bermed edges. At the South Tacoma plant, pile construction involved spray application of approximately 2.5 cm (1.0 in) of septage onto the bed immediately followed by the placement of a thin covering of sawdust using a front end loader. Alternating layers of septage and sawdust were added until the pile reached a height of 2.5 - 3.0 m (8 - 10 ft). Generally, the composting period was from 30 - 90 days (27, 28).

Various wood wastes have been used as an absorbent or bulking material during the composting process: South Tacoma - hardwood sawdust; Bremerton -Douglas fir pole strippings; and Chehalis - alder sawdust. The Chehalis facility has incorporated several design changes, including a leachate collection system with return to the receiving tank, and a mechanized sawdust distribution system, consisting of a hopper, feeder, blower, and hose.

The final compost material has a moisture content of approximately 50 percent. Average values for the nutrient content of Lebo compost are shown in Table 1.

Heavy metals in septage compost do not appear to be of great significance due to the generally low levels of metals found in raw septage. Table 1 compares the characteristics of Lebo septage compost, NPS sanitary toilet waste compost, and Beltsville composts from raw and digested sewage sludge. In general, the metal content is somewhat higher for sludge-derived composts.

TABLE 1

COMPOSITION OF SEPTAGE
AND SLUDGE COMPOSTS

	Lebo(21) Septage Compost	NPS Portable Toilet Waste Compost(23)	Beltsville(20) Raw Sludge Compost	Beltsville(20) Digested Sludge Compost
pH	6.2-7.2	6.1	6.8	6.8
Total N, %	0.9	-	1.6	0.9
Total P, %	0.1	-	1.0	1.0
K, %	0.04-0.29	0.2	0.2	0.1
Ca, %	3.0	2.2	1.4	2.0
Zn, ppm	400	559†	770	1,000
Cu, ppm	50	14.9	300	250
Cd, ppm	10	4.7	8	9
Ni, ppm	100	-	55	-
Pb, ppm	60	192	290	320

† NPS portable toilet waste reflects an elevated zinc level due to the addition of a zinc based disinfectant during the pumping-recharge operation of the toilets.

This trait appears to be characteristic of municipal sludges vs wastes from sanitary toilets or septic tanks.

Bacteriological data are presented in Table 2. The concentration of total and fecal coliforms in National Park Service (NPS) compost appears to be somewhat lower in bacterial concentrations than the Lebo and Beltsville composts.

National Park Service

In June of 1976, NPS began composting wastes collected from 40 to 50 portable toilets located along the towpath of the Chesapeake and Ohio Canal National Historical Park (C&O Canal) in Maryland.

The length of the composting cycle was somewhat flexible. Generally, a 3 week composting cycle was considered sufficient to render the product safe. This was usually followed by stockpiling for 6 months or more. Management requirements at the C&O Canal were such that composting was allowed to proceed for 4 to 5 weeks. Since waste generation and the need for waste treatment has the same seasonal variation as visitation, setup-teardown cycles can be lengthened.

A portion of the compost product was generally reused during the composting cycle as a bulking agent. The C&O Canal has recognized the value of its product and found it could use considerably more product than the site generated.

Preliminary data collected from the C&O Canal composting operation during 1976-77 are presented in Tables 1 and 2. Temperatures attained in any composting pile usually exceeded the 55°C range necessary to ensure adequate destruction of pathogens. However, it should be noted that the highest temperatures are probably indicative of temperatures within the center of the pile, and that temperatures toward the outer surfaces or near the air distribution system may be somewhat lower.

Rehoboth, MA

A short term pilot project in Rehoboth, MA. investigated composting of septage-sawdust-woodchip mixtures by using both the Beltsville static pile (forced aeration) method as well as by manual turning of the piles. Composting of septage was considered after the closing of the Fall River, MA. treatment plant, which forced the towns of Rehoboth, Seekonk, and Swansea to seek other alternatives for disposing of these wastes (17, 18).

The project commenced on May 12, 1977, and terminated in July of that year. Five piles were constructed and monitored. Table 3 presents a breakdown of the constituents of each of the five piles.

Internal temperature data for each of the three forced aeration composting piles indicated that active composting was occurring. It was noted that the temperatures achieved in pile #2 were somewhat higher than those in piles 1 and 5, perhaps due to the greater quantity of manure incorporated into the mixture, resulting in a lower C:N ratio.

TABLE 2

MICROBE CONTENT OF COMPOSTS
MPN/g

	Total Coliforms	Fecal Coliforms	Salmonella sp.
1. LEBO(27)			
a. Raw Septage	2.4×10^4/g	4.3×10^3/g	--
b. Compost	46/g	0.4/g	--
2. NPS(23)			
a. Raw toilet waste	--	--	neg.
b. Cured compost	4.0×10^3/g	3.5×10^2/g(24)	neg.
3. Beltsville (11)			
a. Raw sludge	3.9×10^8/g	1.6×10^7/g	37/g
Compost	580/g	9.48/g	<8/g
b. Digested sludge	5.8×10^7/g	2.6×10^6/g	5.5/g
Compost	54,057/g	702/g	0.5/g

TABLE 3

MATERIALS USED IN CONSTRUCTION OF PILOT COMPOST PILES
REHOBOTH, MA (18)

Pile #1 - Forced aeration
Date constructed: May 12, 1977
1000 gallons septage
6 cubic yards sawdust
3 cubic yards woodchips
1 cubic yard cow manure

Pile #2 - Forced aeration
Date constructed: May 18, 1977
800 gallons septage
5 cubic yards sawdust
2 cubic yards woodchips
3 cubic yards horse manure

Pile #3 - Forced aeration
Date constructed: May 25, 1977
1050 gallons septage
4 cubic yards sawdust
4 cubic yards woodchips
1.5 cubic yards cow manure

Pile #4 - Forced aeration
Date constructed: June 9, 1977
1000 gallons septage
4 cubic yards sawdust
3 cubic yards woodchips
2 cubic yards cow/horse manure

Pile #5 - Forced aeration
Date constructed: June 16, 1977
1000 gallons septage
2 cubic yards sawdust
2 cubic yards finished compost (Pile #1)
3 cubic yards woodchips
1 cubic yard horse/cow manure

No bacteriological data was collected during the course of this pilot project. In some cases, the temperatures did not appear to have been maintained at sufficiently high values to ensure complete pathogen destruction. This may be due to several factors, including excessive C:N ratios supporting limited bacteriological activity, insufficient oxygen transfer, or nonhomogeneity of the pile contents caused by insufficient mixing. The investigator attributed variations in temperature within the piles to the latter (17).

U.S. Forest Service Composting

U.S. Forest Service scientists in Durham, NH. have developed a highly successful bin composting innovation for backcountry use. Previously, several "self composting" toilet systems had been utilized within similar backcountry or remote sites (13, 15, 16). However, the high unit costs of the self composting systems led to the development of the bin composting technique. These bins were located adjacent to individual toilet systems and were used to compost the wastes collected from single toilets. Bins were prefabricated boxes which were easily backpacked to remote sites and assembled. Barkchips were carried to the site and placed in the bin. Liquid waste from individual toilet systems were transferred onto the barkchips. The mixture was then blended using a manure fork and composting was initiated. Generally, 3 to 4 weeks were required for proper treatment. Composting in this fashion was very dependent upon ambient temperatures, and the characteristics and relative volumes of waste handled. Aeration of the composting mixture was enhanced by small diameter PVC pipes placed through the sides of the bins and extending through the waste bark mixture. Compost generated was used onsite to reduce human impact on heavily used areas.

SECTION 4

MATERIALS AND METHODS

Aerated static pile composting technology has been well described in the literature (9, 10, 11, 22, 23). In 1975 and 1976, the C&O Canal modified the composting system developed by the U.S.D.A. at Beltsville to treat raw liquid waste materials. Due to the lack of dewatering facilities, combinations of bulking materials were selected which were quite absorbent and which maintained suitable porosity within the pile. Such materials included woodchips, sawdust, leaves, and occasionally other materials. Compost piles were considerably smaller than those constructed at Beltsville by the U.S.D.A.; however, with positive control over aeration and selection of the proper ratio of absorptive organics, a workable blend of materials was achieved.

Considerable experience and success was gained during 1976-1978 with treatment of raw waste materials such as sanitary toilet pumpings, septage, and mixtures of each.

In 1978, EPA initiated a research project with NPS to fully evaluate this adaption of the composting technique. An experimental design was proposed to perform three compost runs for each of the two waste materials. Two compost piles were to be erected on the same date, one with sanitary toilet waste and one with septage. Thus, a total of 6 compost piles were analyzed. On each setup date, samples were taken of both raw wastes. During active composting, samples from within each pile were taken at weekly intervals and subjected to full laboratory characterization.

Site Description

The C&O Canal acquired new land during the 1960's through the Land Acquisition Program. Criteria used for final site selection were: 1) isolation from view of visitor activities; 2) nearly level ground, preferably with no large trees; 3) permeable soil with seasonal high water table at least 1.2 m (4 ft) below the soil surface; 4) location near the mid-point of the administrative district for convenience; 5) elimination of interference with future park development; and 6) other less restrictive parameters.

These constraints, along with site-specific characteristics, were compiled into an Environmental Assessment in 1975 which received input from the National Park Service and appropriate state agencies (1).

Estimates of the waste production for previous years were used to determine site size. About 0.4 ha (1 ac) of land was designated as the pad and storage site. Around the perimeter of the pad a diversion ditch was constructed to carry any upslope runoff safely away from the composting site. A basin was excavated immediately downslope from the pad such that it would receive any onsite runoff for possible treatment. The compost pad size was 20 m X 46 m (65 ft x 150 ft). One end of the pad was designated for woodchip, leaf, and sawdust storage while the finished compost was stored nearby (Figure 1).

The rectangular design of the main working pad was such that six or more working compost piles could be located parallel to the rear edge of the pad. Appropriate flexible 10 cm (4 in) corrugated polyethylene tubing and connections were placed to eliminate interference with front-end loader operations. A single length of solid tubing was run along the rear edge of the pad with feeder lines to individual compost piles. Feeder lines were capped until such time as needed. Once a cap was removed, a 10 cm wood stove pipe damper was installed into each feeder line to control air flow.

At the end of the pad opposite from the storage area, a mixing basin and holding tank were installed. The mixing area was originally native soil covered with a layer of bluestone. In 1979, this mixing area was surfaced with concrete. The first holding tank (1000 gal) was placed below ground level during the summer of 1976. This allowed onsite storage, reduced load volumes on the pumper truck, and created a more efficient composting operation in that larger piles were built at less frequent intervals. During 1979 a new holding tank (2000 gal) was constructed above the concrete surface allowing waste to be gravity fed to the mixing site. Although the small sized compost piles functioned well for the operational needs of the C & O Canal, it was felt that larger compost piles made possible by increased holding tank capacity would free manpower for other necessary duties. The compost site and modification are shown in (Figure 1).

Acquisition of the Waste

The C&O Canal is about 292 km (185 miles) in length and is divided into three maintenance districts. Paralleling the C&O Canal for this length is a towpath along which are located sanitary toilet facilities. At designated access points to the Potomac River there are picnic areas, hiker-biker camping sites, boat ramps, etc. At these sites there may be three or more sanitary toilet facilities. Toilets used along the C&O Canal are portable 230 ℓ (60 gal) capacity units. Use of these sanitary facilities is dependent upon the season of the year and general weather conditions; i.e., more favorable weather necessitates a greater pumping frequency. The crew which operates the pumper truck also manages the compost site. They are also responsible for trash pickup along the towpath, at visitor use facilities, and numerous other duties.

During the first year of operation in 1976, most of the minor functional problems were solved and efficient composting achieved. Bulking material ratios were established with respect to waste amounts. During the first season of operation, 25,740 ℓ (6,800 gal) of waste were treated. The quan-

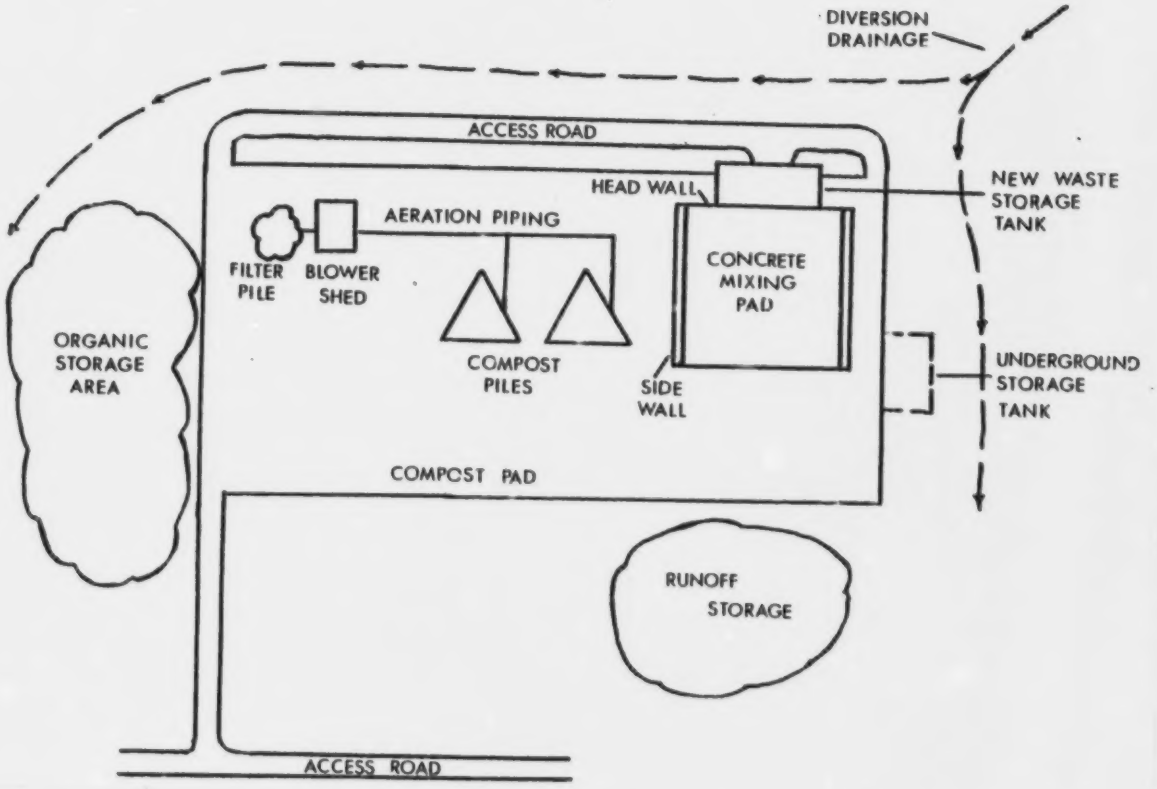


Figure 1. C&O Canal Compost Site - Final Layout

tities of organic materials used for mixing with liquid waste were: 7.4 cu m (9.7 cu yd) woodchips; 7.4 cu m (9.7 cu yd) sawdust; and 3.2 cu m (4.2 cu yd) compost per 3,785 (1,000 gal) of waste. It is important to mention that these quantities represent only the "active" portion of the pile, and may vary depending upon the moisture content of each bulking agent and the characteristics of the waste. Other bulking materials may be equally functional.

Compost pile size was approximately 4.5 m (15 ft) in diameter by 2.7 m (9 ft) high. During the 3 to 4 week compost cycle, the pile settled to a final height of 1.8 m to 2.1 m (6 - 7 ft).

During the second season (1977) approximately 35,200 ℓ (9,300 gal) of waste was treated. On occasion during the first 2 years of operation, some septage was treated at the site. Within the C&O Canal are several park residences that use septic systems for wastewater treatment and disposal. The decision was made to attempt to compost a mixture of sanitary toilet waste and septage. The first compost pile constructed with this combination of wastes did not function as well as the sanitary toilet waste alone. The final product, however, appeared similar to the sanitary waste compost and since that time septage has been effectively composted with little problem.

Description of Composting Operation

The composting operation as practiced at the C&O Canal, utilized various mixtures of bulking agents (woodchips, leaves, compost, and sawdust) to absorb the large volume of liquid in the waste. Bulking organics were blended into a homogeneous mixture and placed on the mixing pad in an elevated saucer-like configuration. Waste which was stored at the site in a 3,785 ℓ (1,000 gal) holding tank was then distributed onto the bulking organics. (Prior to installation of the gravity fed tank, waste had to be pumped back into the tank truck and fed onto the bulking organics). This mixture was allowed about 1/2 hour for complete absorption to occur. During the interim, a mattress was prepared at an adjacent location on the compost pad. Mattress composition was of previously composted materials to maximize absorption of liquids. An oval of 10 cm (4 in) flexible corrugated polyethylene tubing was laid on the mattress and the ends joined at a "T" or "Y." A length of solid tubing was connected to the remaining end of the "T" and ultimately connected to the intake manifold of the blower. This configuration allowed air to be "pulled" through the compost pile. A stove pipe damper was located in the solid tubing to provide positive draft control. (This was particularly important since more than one pile was handled by a single blower). The perforated oval of tubing located on the mattress had a layer of woodchips placed over it. Woodchips placed in this manner prevented clogging of the perforations (intake holes) in the tubing as composting proceeded.

A small pile of previously composted materials was placed over the terminus of the blower discharge tubing to absorb any odors which may have been present in the discharge gas (Fig. 2).

Thorough mixing of the waste and bulking materials was accomplished by a frontend loader such that a homogeneous "wet mix" was obtained. The wet mix was then transferred from the mixing-absorption area onto the mattress by the

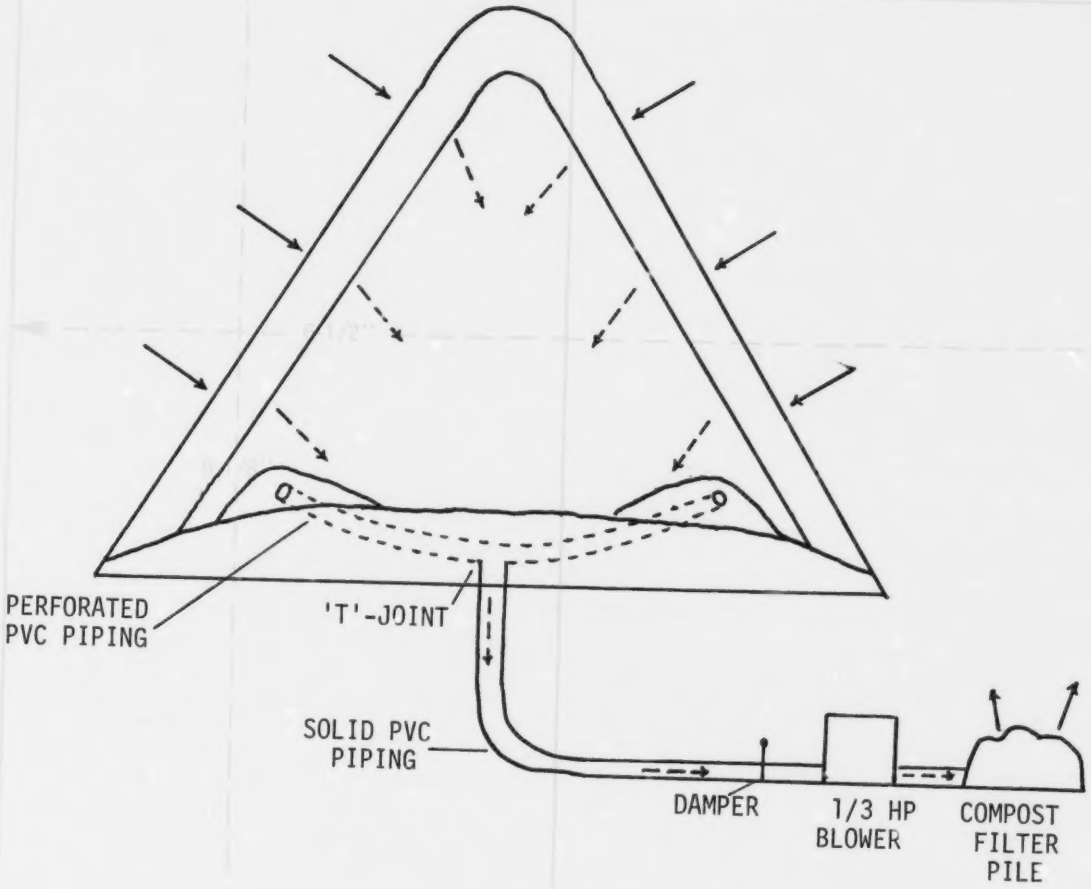


Figure 2. Static Pile Composting System - Air Movement

loader to form an inverted cone. A 30 cm (12 in) blanket of compost was placed over the pile to provide insulation of the composting pile. During the course of the study, it was found that a thicker blanket 46 cm (18 in) was required for septage (Fig. 3). This is discussed in greater detail later in the report.

Quality control at the site was absolutely critical if proper composting was to be accomplished. Site cleanliness and proper handling of raw waste dictate the success or failure of the composting operation and ultimately, the safety of the final product.

Temperature and Oxygen Monitoring

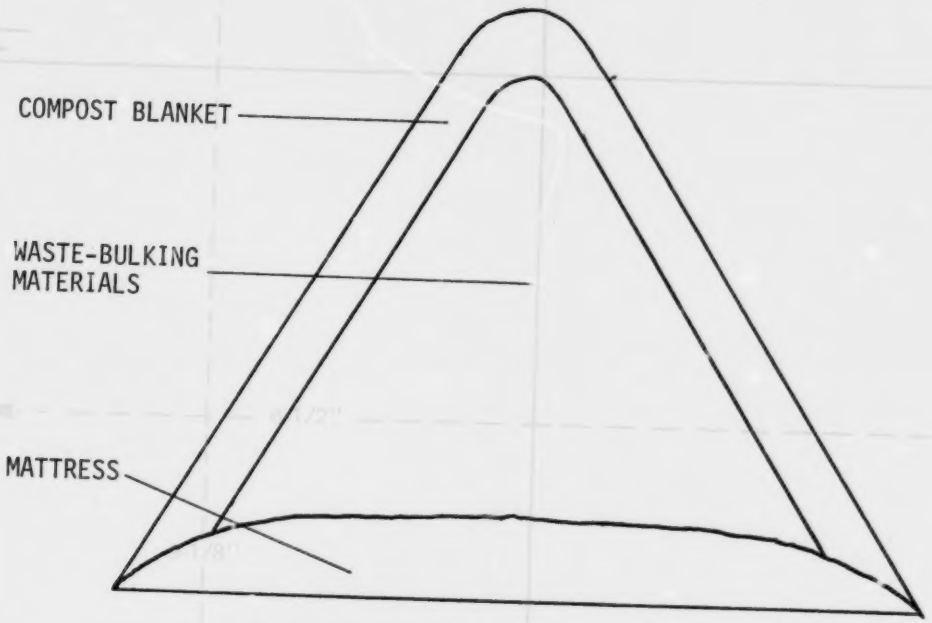
During the composting cycle, the temperature at various points within the mixture was monitored once each working day. Dial thermometers, 92 cm (36 in) in length, were used to monitor the internal compost pile temperatures. The thermal sensitive tips of these thermometers responded quickly to internal pile temperature. Longer probe type thermometers or thermocouples could be used for larger composting systems.

Oxygen analyses were conducted once each working day using a portable oxygen analyzer equipped with a 5 foot stainless steel probe. Oxygen was withdrawn from the pile by use of suction and the meter reading recorded for each of the preselected pile locations. Temperature and oxygen measurements were made on 4 sides of each pile at 3 depths per location, e.g., 48 locations per pile.

Sampling Procedure

Sampling of untreated sanitary toilet waste was accomplished during the pumping operation immediately prior to compost pile setup. Subsamples of each raw waste were collected from the initial discharge, midway during waste discharge, and finally near the end of the discharge. These samples were blended to form a composite sample then split, half being sent to a commercial laboratory and half to the ESL for analysis. These samples were analyzed for BOD, COD, total coliforms, fecal coliforms, Salmonella sp., total solids, total volatile solids, pH, soluble salts, total Kjeldahl nitrogen, total phosphorus, total potassium, cadmium, copper, lead, nickel and zinc.

To obtain appropriate compost samples from internal pile locations without major disturbance of the composting mixture, access pipes were installed at known locations within the pile during pile construction (Fig. 4). These access pipes extended only to the outer edge of the composting mixture, were capped, and covered by the blanketing materials. The blanketing materials served to protect against excessive heat loss during composting. Location of access pipes were marked using engineer's flags. Compost samples were withdrawn from the four locations around the pile by use of a sterilized auger inserted into the pile through the access tubes. Each tube was located at a different elevation on the pile and the pipes varied in length to ensure sampling of potential problem locations. These locations were randomized throughout the three separate compost setups (Fig. 4).



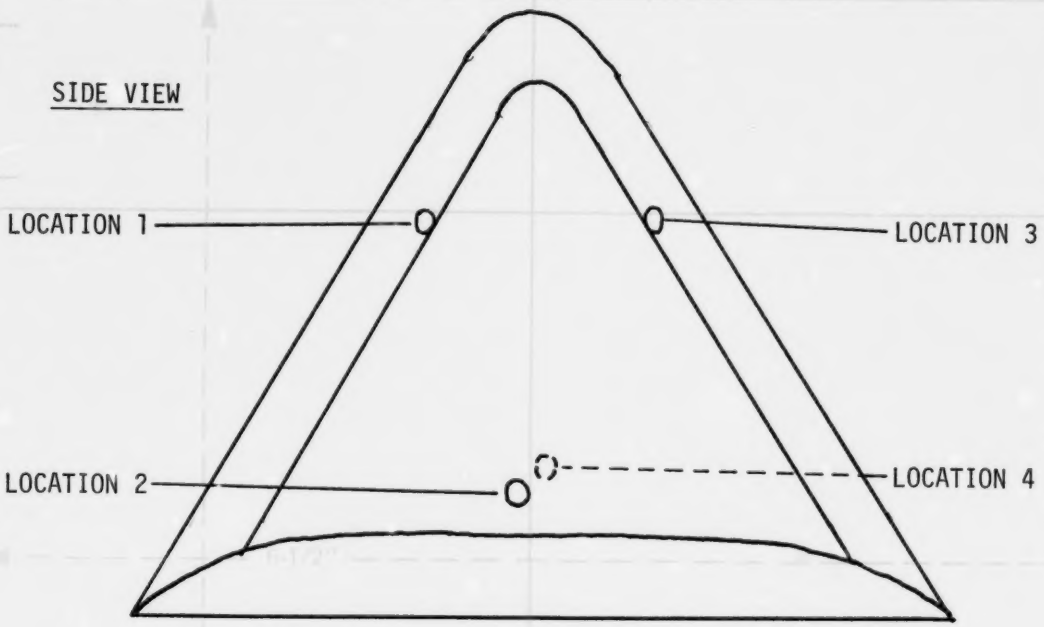
BLANKET & MATTRESS - WOODCHIPS & PREVIOUSLY COMPOSTED MATERIAL

BULKING MATERIAL - WOODCHIPS, SAWDUST, & PREVIOUSLY COMPOSTED MATERIAL

SEPTAGE PILE DIMENSIONS
2.7 M (9FT) HIGH
4.6 M (15FT) DIAMETER
0.3 M (12") MATTRESS
0.5 M (18") BLANKET

SANITARY WASTE PILE DIMENSIONS
2.7 M (9FT) HIGH
4.6 M (15FT) DIAMETER
0.3 M (12") MATTRESS
0.3 M (12") BLANKET

Figure 3. Static Pile Composting System - Pile Composition



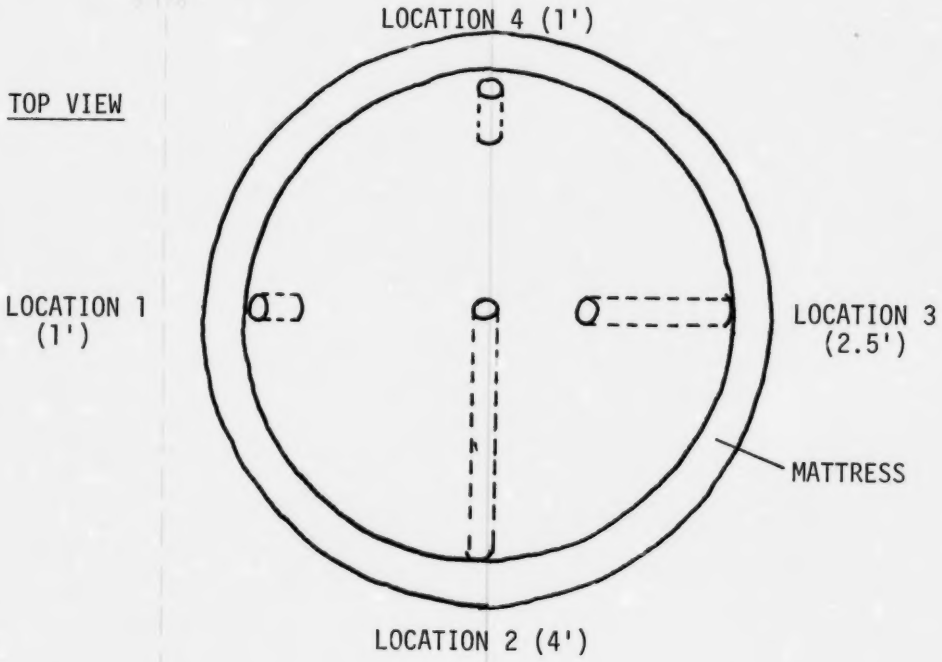
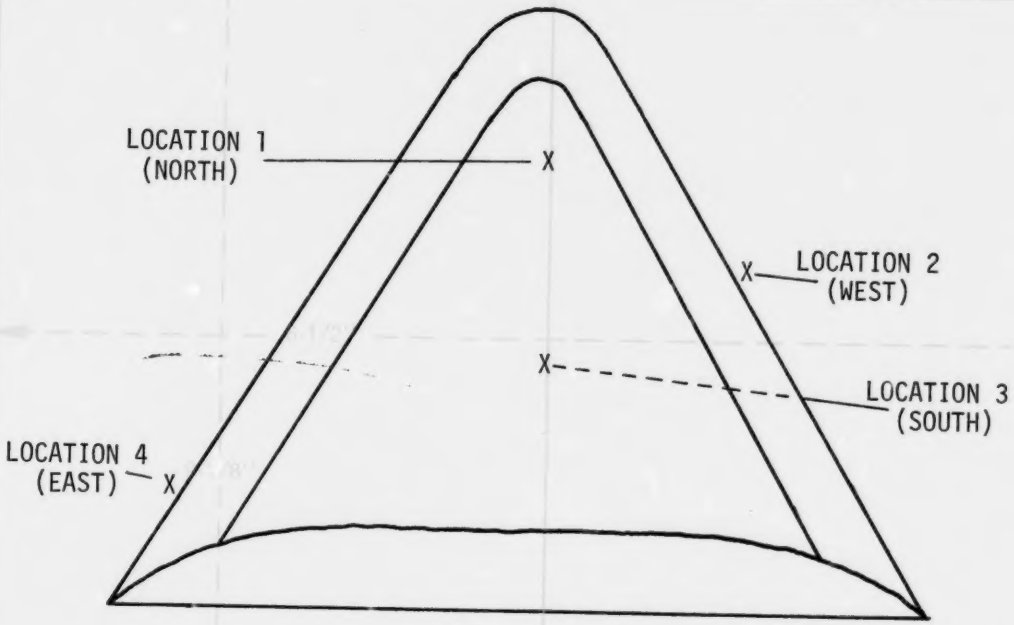


Figure 4. Static Pile Composting System - Sampling Locations

Temperature and oxygen contents were monitored every working day at 48 locations within each pile through the three composting runs. These data were collected at depths of 30 cm (1 ft), 60 cm (2 ft), and 90 cm (3 ft) into the compost pile at 4 locations on each of the four sides of the pile (Fig. 5). Temperature data for the mean values were summarized across the 3 compost runs and at the 4 similar locations on the pile - each data point on the graph represents 12 individual field data points. Maximum and minimum levels are single points and are presented to illustrate the extremes. These data are illustrated in Figures 6 through 21.

Laboratory characterization of several parameters were conducted by a private laboratory on both raw waste and compost pile contents. Those parameters characterized were: biochemical oxygen demand (BOD), chemical oxygen demand (COD), total coliforms (TC), fecal coliforms (FC), Salmonella sp., total solids (TS), and total volatile solids (TVS). These analyses were conducted according to Standard Methods for the Examination of Water and Wastewater (4 and 26).



TEMPERATURE AND OXYGEN
MONITORED AT THREE DEPTHS
(.3,.6,.9M) AT EACH OF FOUR LOCATIONS
AROUND THE PILE

Figure 5. Static Pile Composting System - Temperature and Oxygen - Monitoring Locations

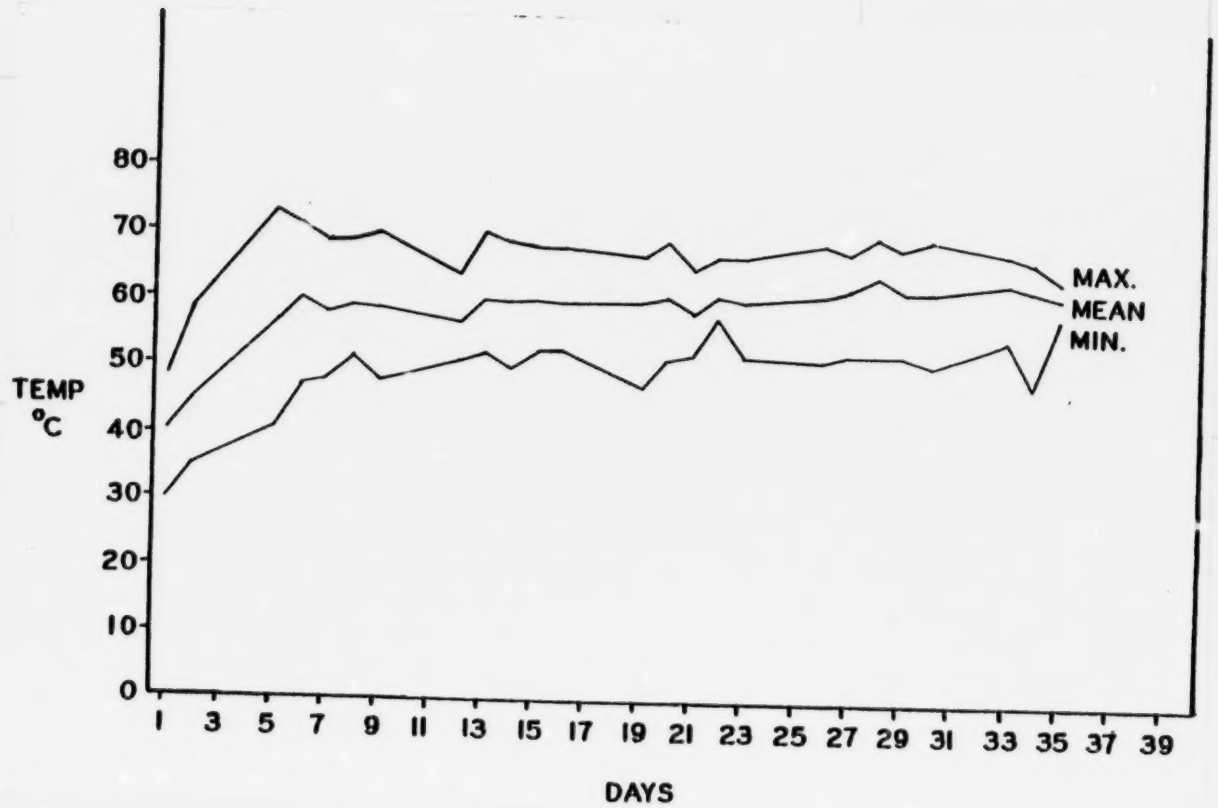


Figure 6. Temperature in Sanitary Compost Pile vs. Time
Location 1 - Depth 30 cm

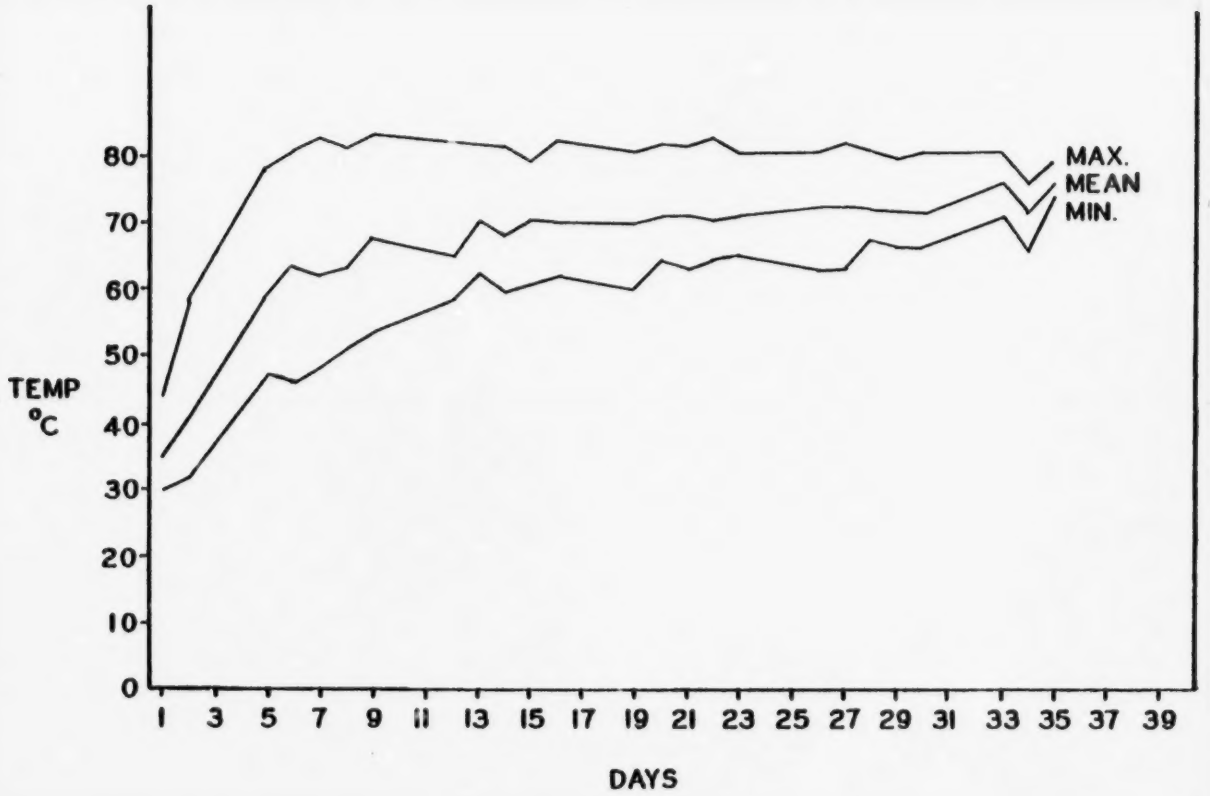


Figure 7. Temperature in Sanitary Compost Pile vs. Time
Location 1 - Depth 90 cm

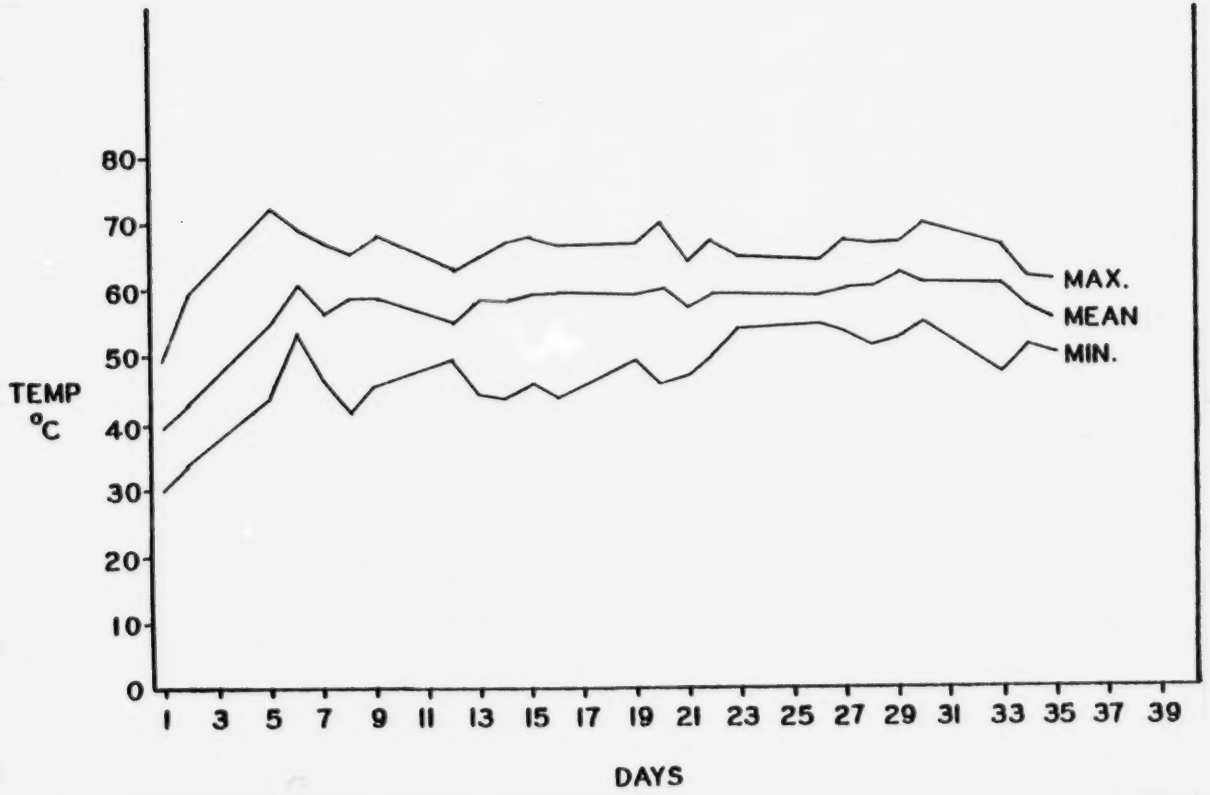


Figure 8. Temperature in Sanitary Compost Pile vs. Time
Location 2 - Depth 30 cm

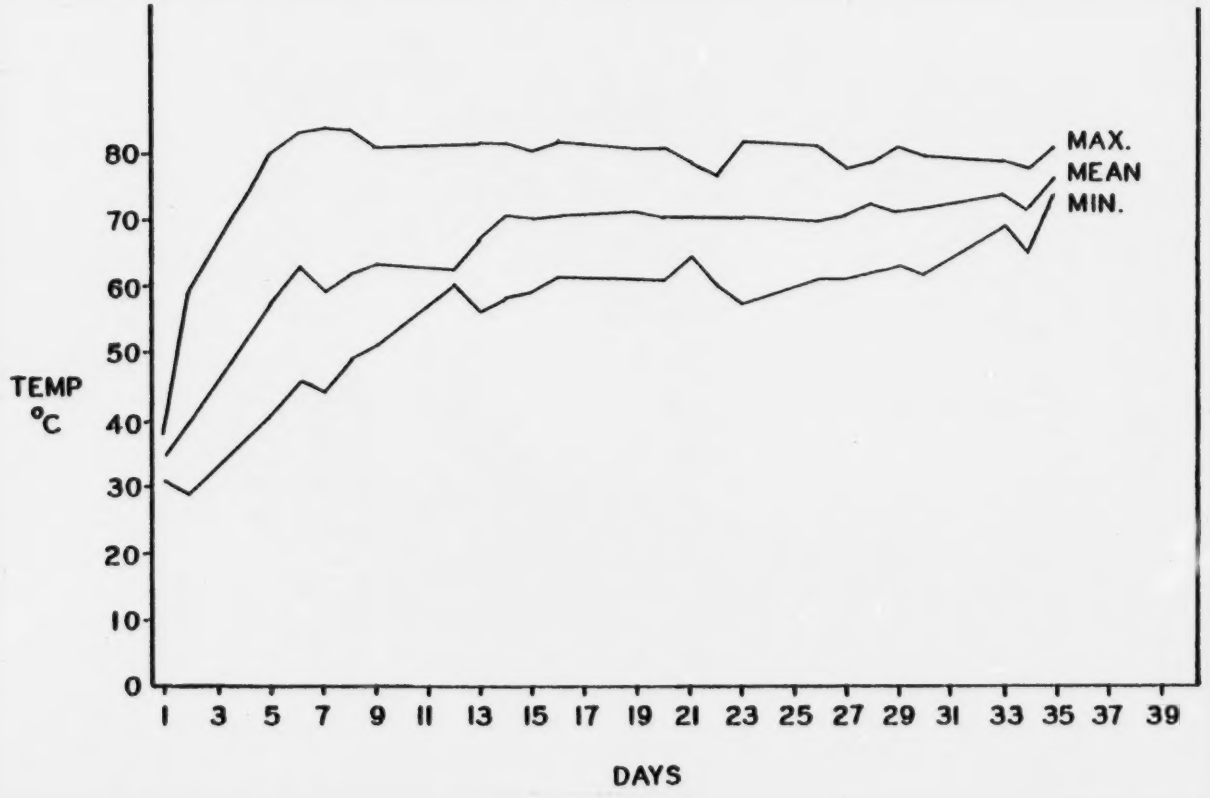


Figure 9. Temperature in Sanitary Compost Pile vs. Time
Location 2 - Depth 90 cm

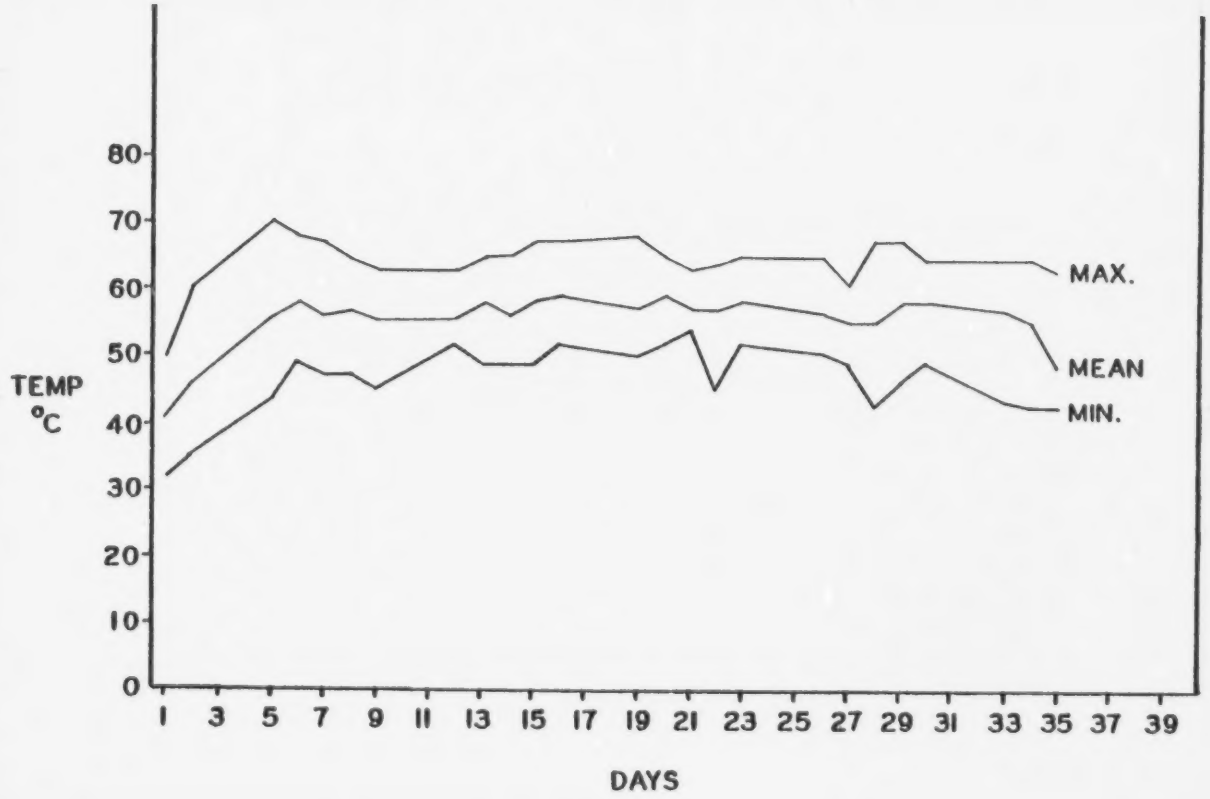


Figure 10. Temperature in Sanitary Compost Pile vs. Time
Location 3 - Depth 30 cm

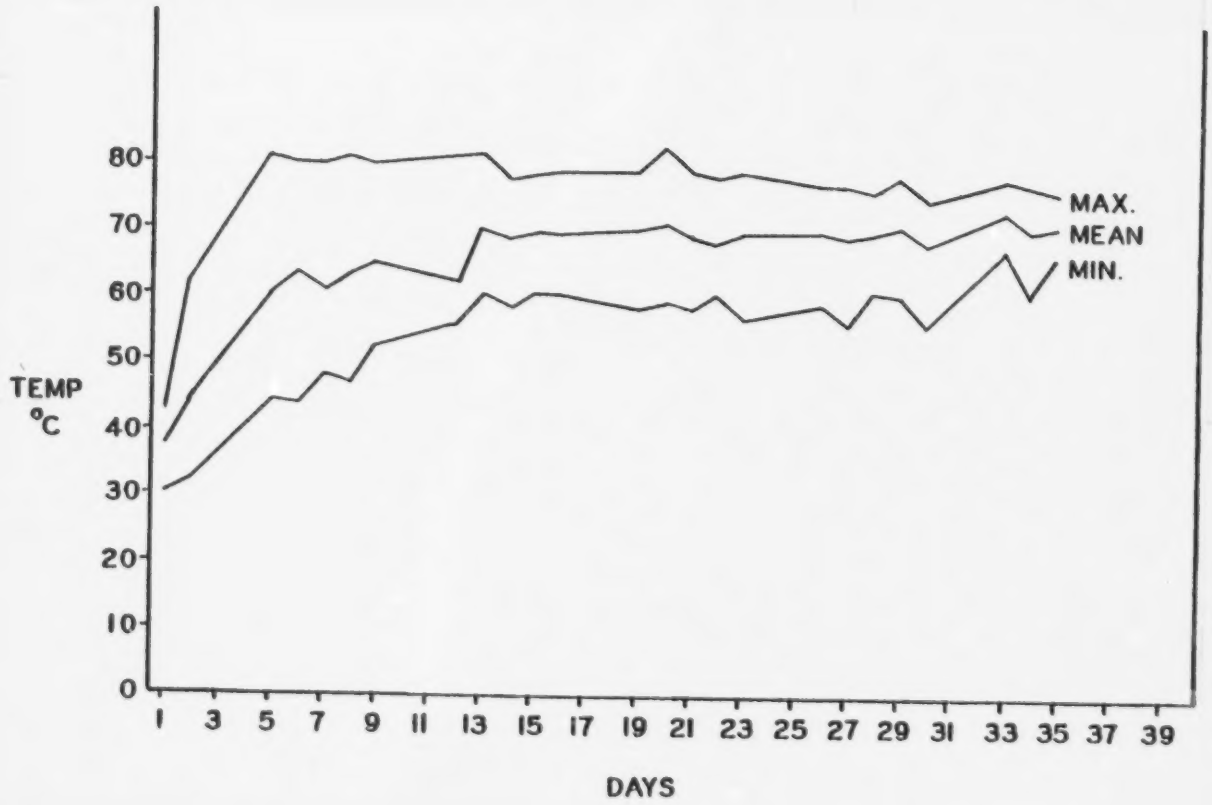


Figure 11. Temperature in Sanitary Compost Pile vs. Time
Location 3 - Depth 90 cm

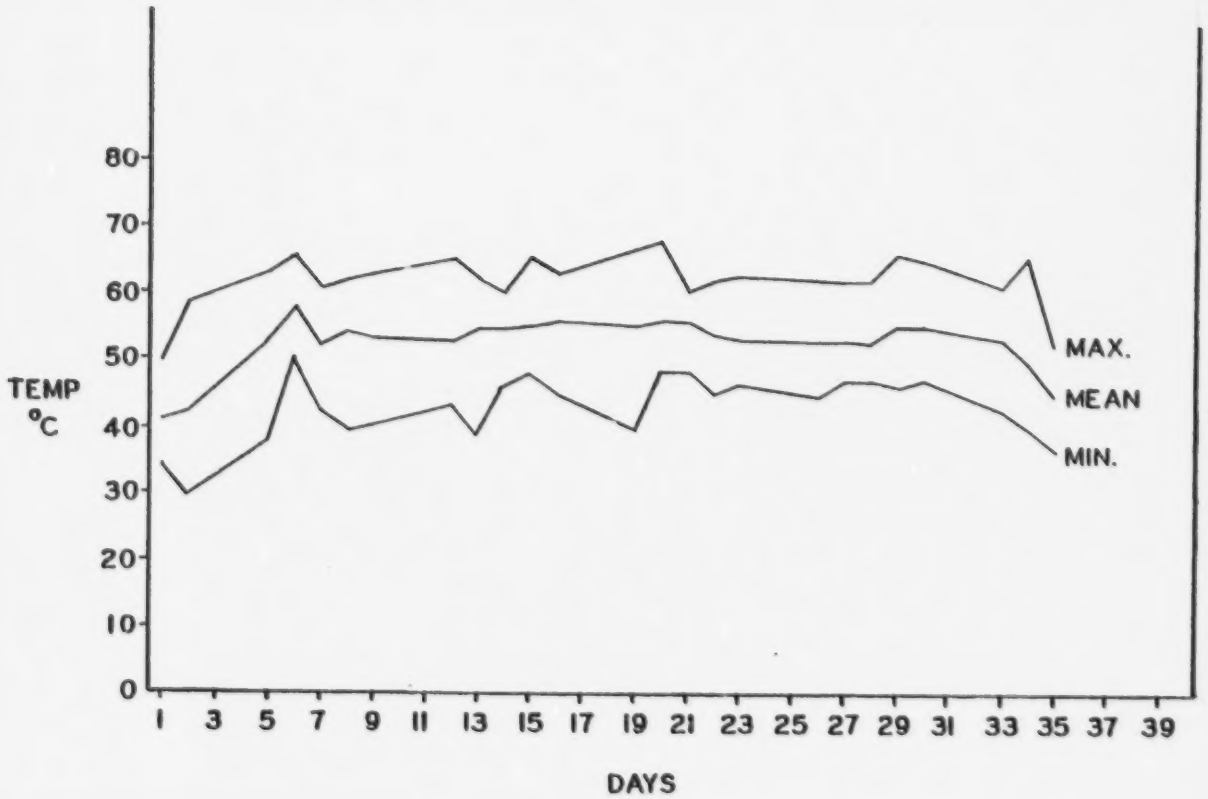


Figure 12. Temperature in Sanitary Compost Pile vs. Time
Location 4 - Depth 30 cm

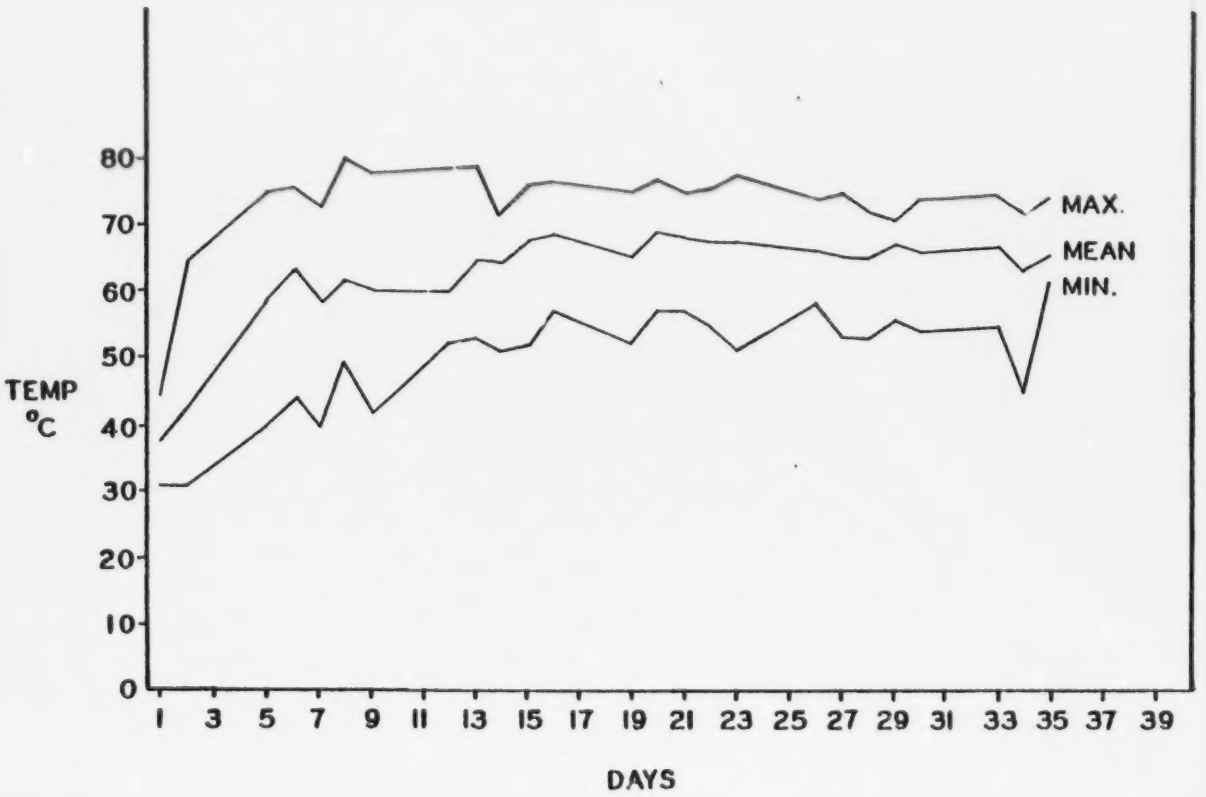


Figure 13. Temperature in Sanitary Compost Pile vs. Time
Location 4 - Depth 90 cm

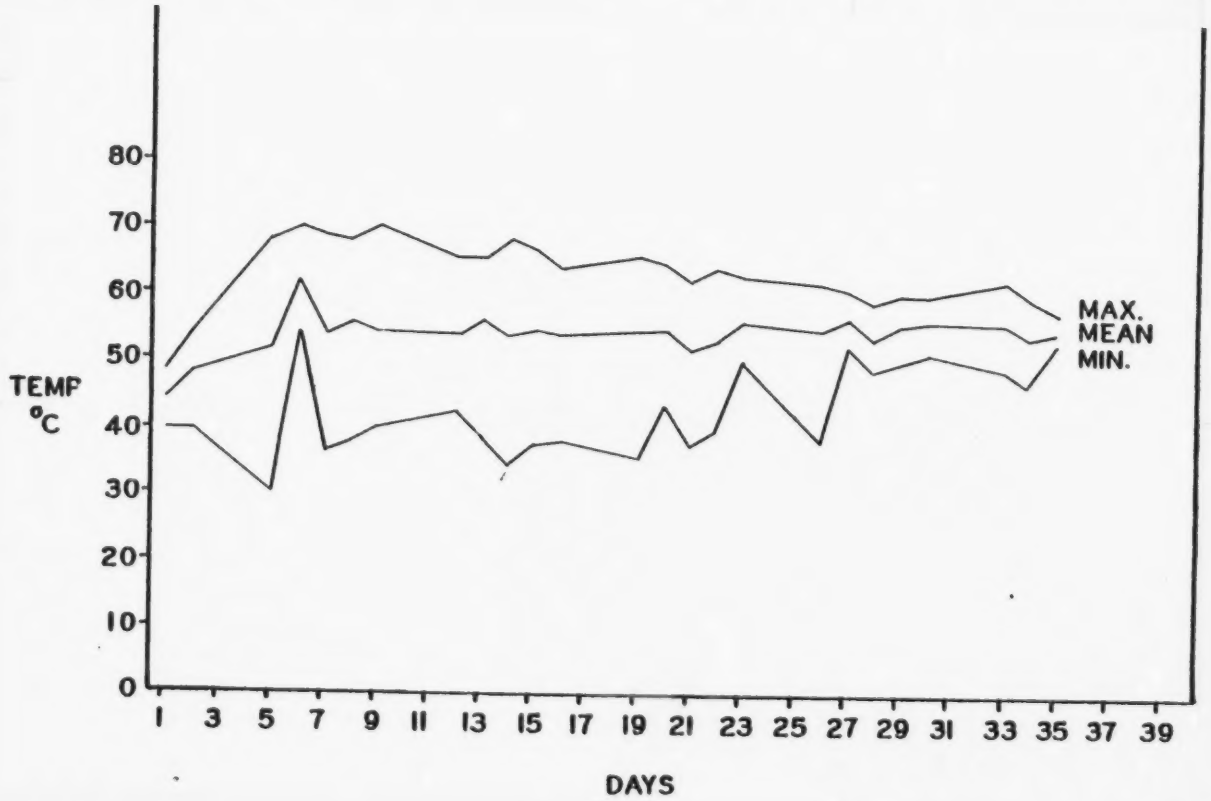


Figure 14. Temperature in Septage Compost Pile vs. Time
Location 1 - Depth 30 cm

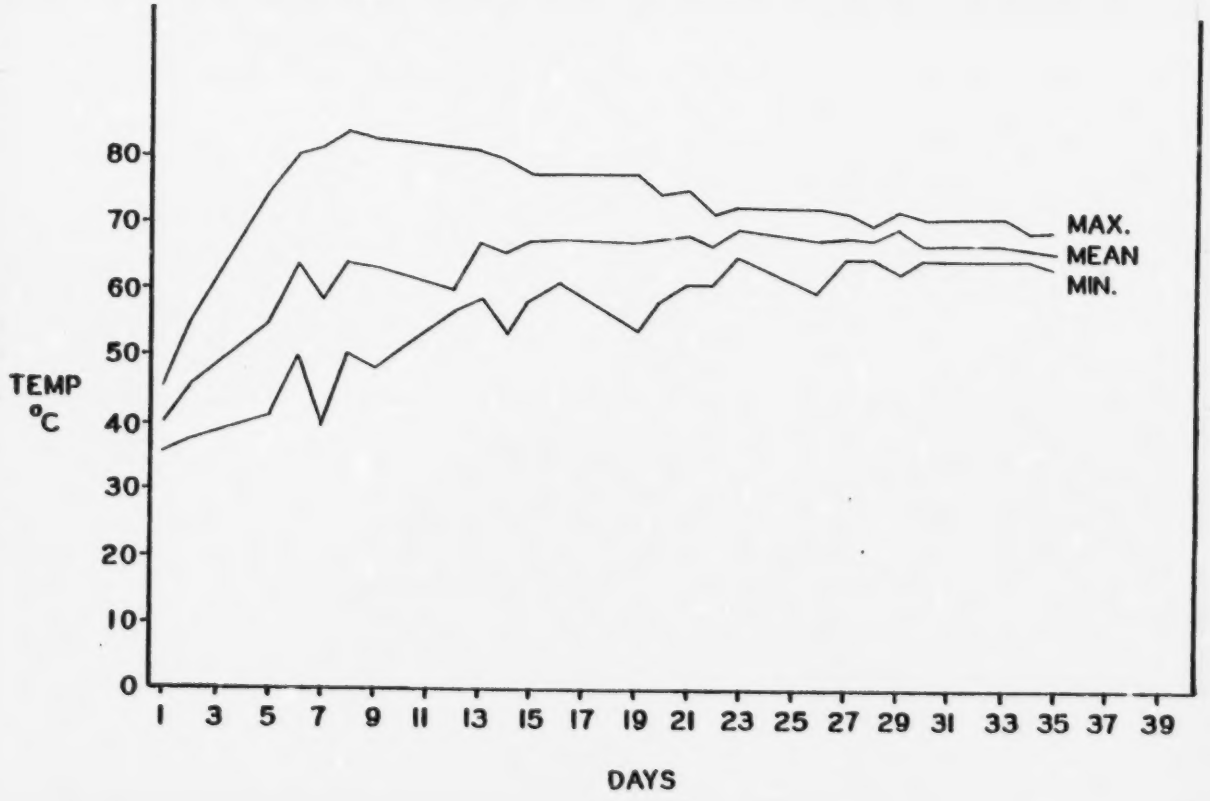


Figure 15. Temperature in Septage Compost Pile vs. Time
Location 1 - Depth 90 cm

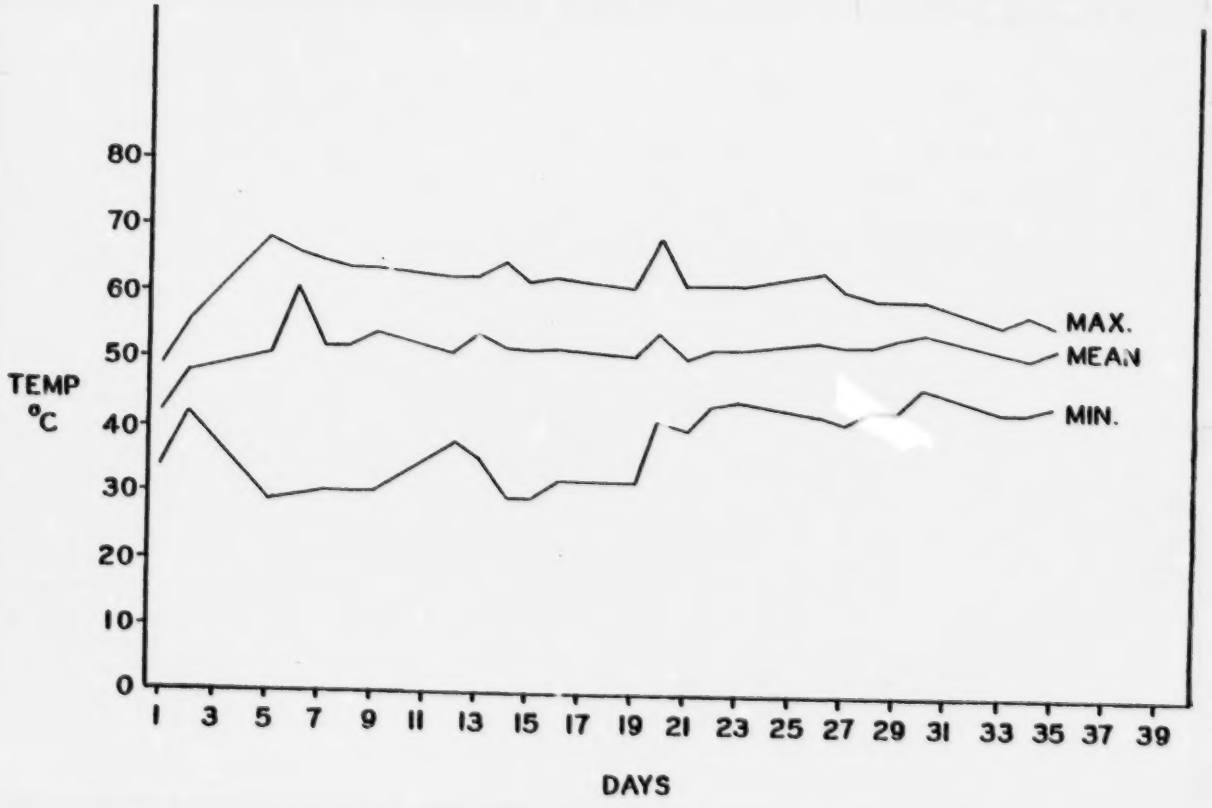


Figure 16. Temperature in Septage Compost Pile vs. Time
Location 2 - Depth 30 cm

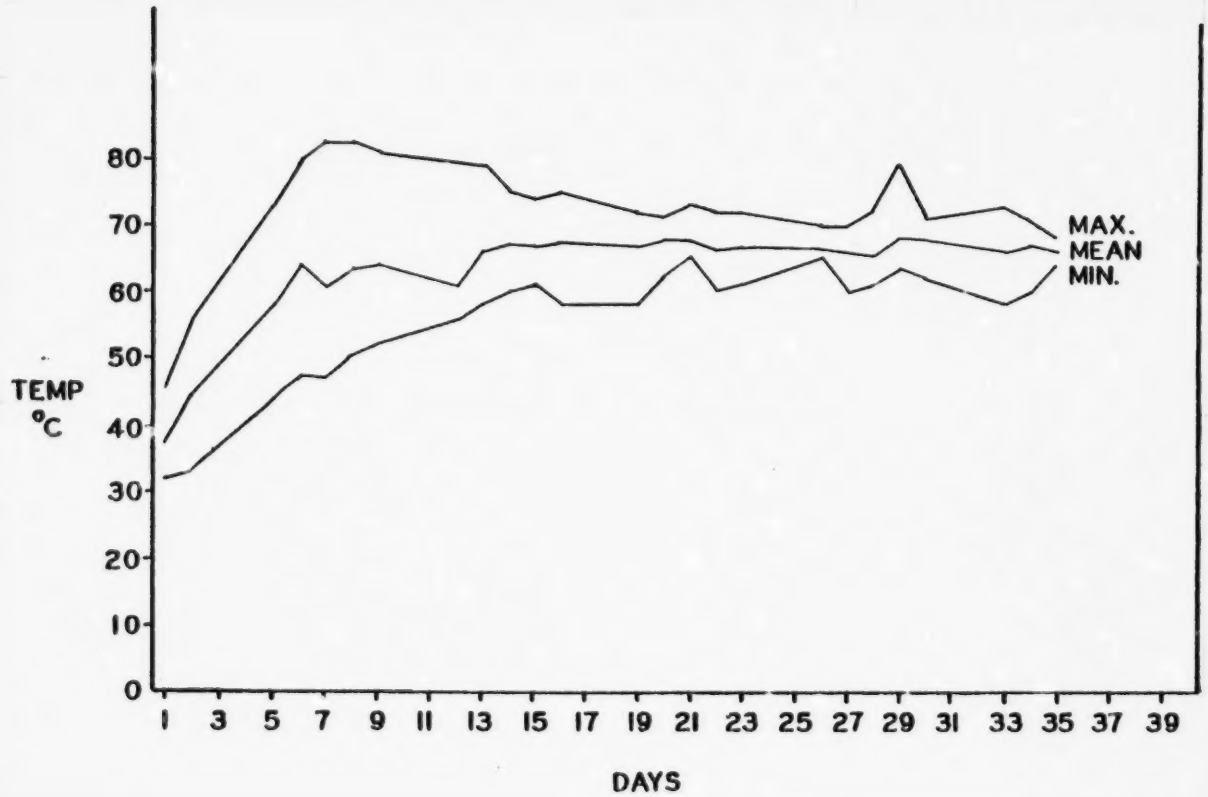


Figure 17. Temperature in Septage Compost Pile vs. Time
Location 2 - Depth 90 cm

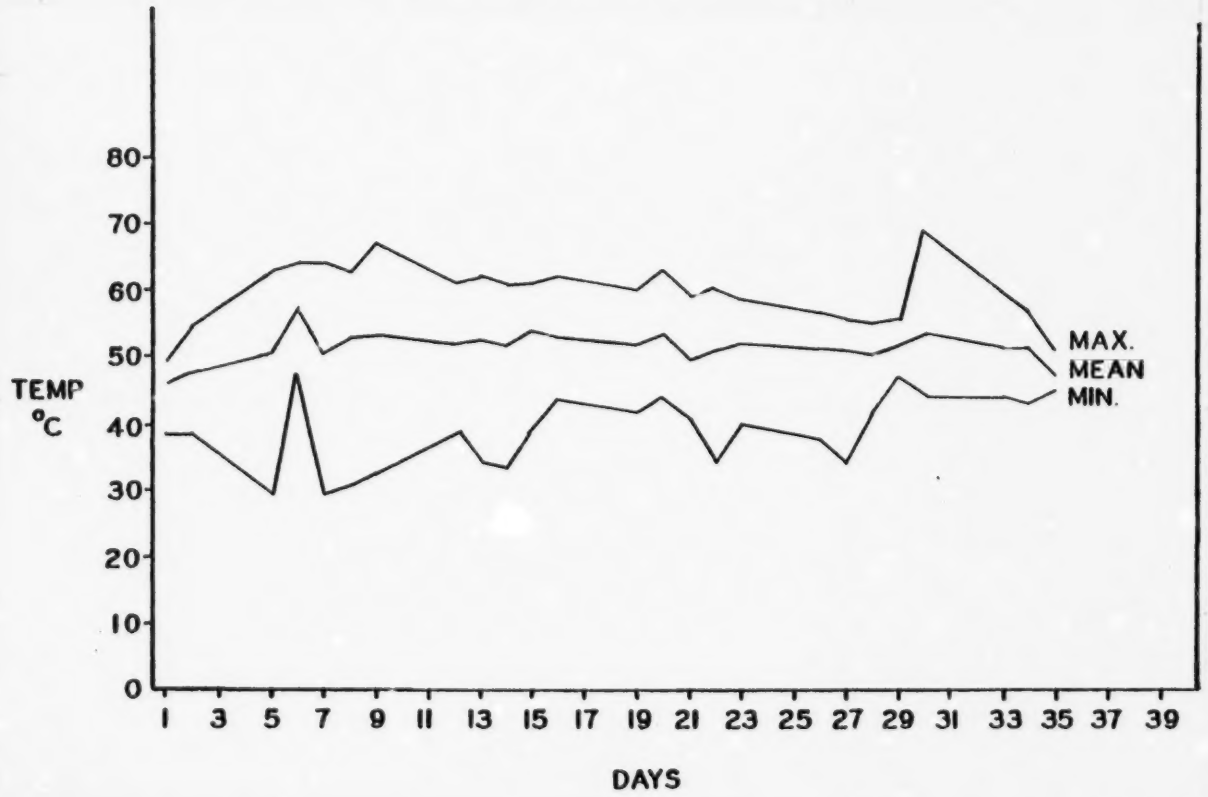


Figure 18. Temperature in Septage Compost Pile vs. Time
Location 3 - Depth 30 cm

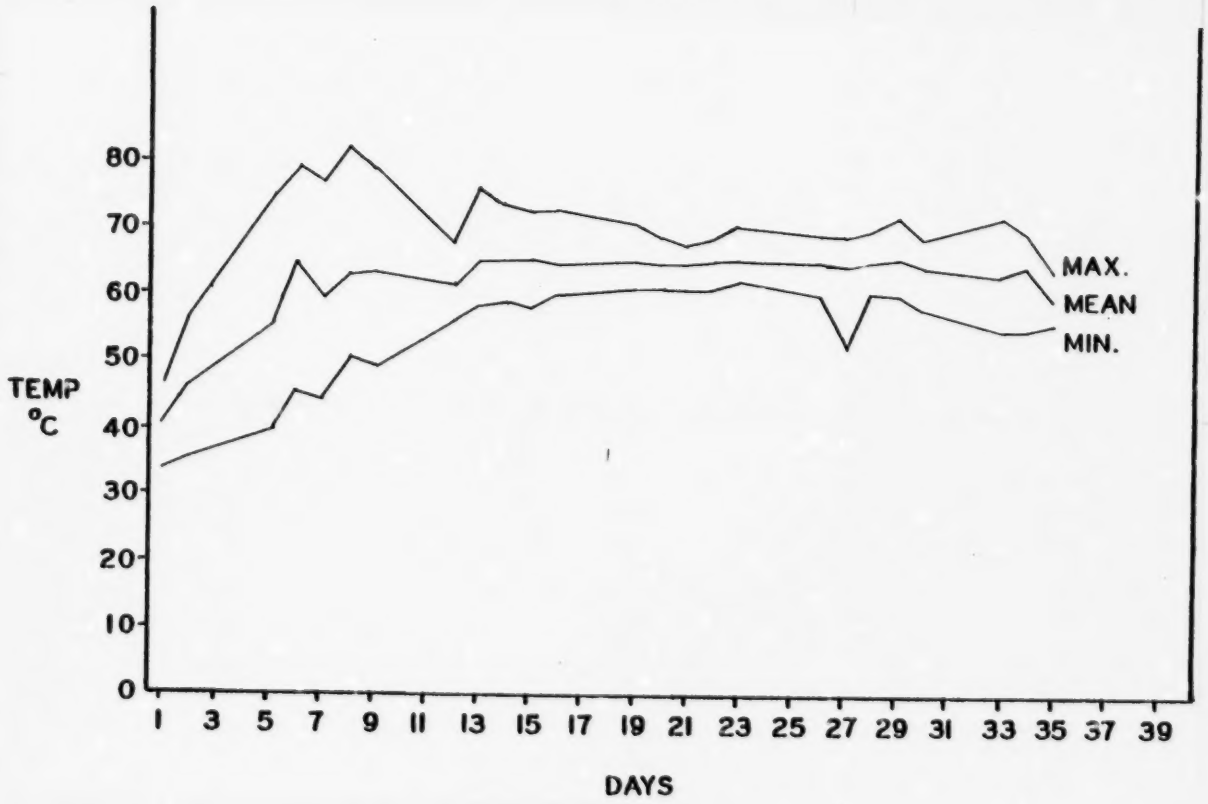


Figure 19. Temperature in Septage Compost Pile vs. Time
Location 3 - Depth 90 cm

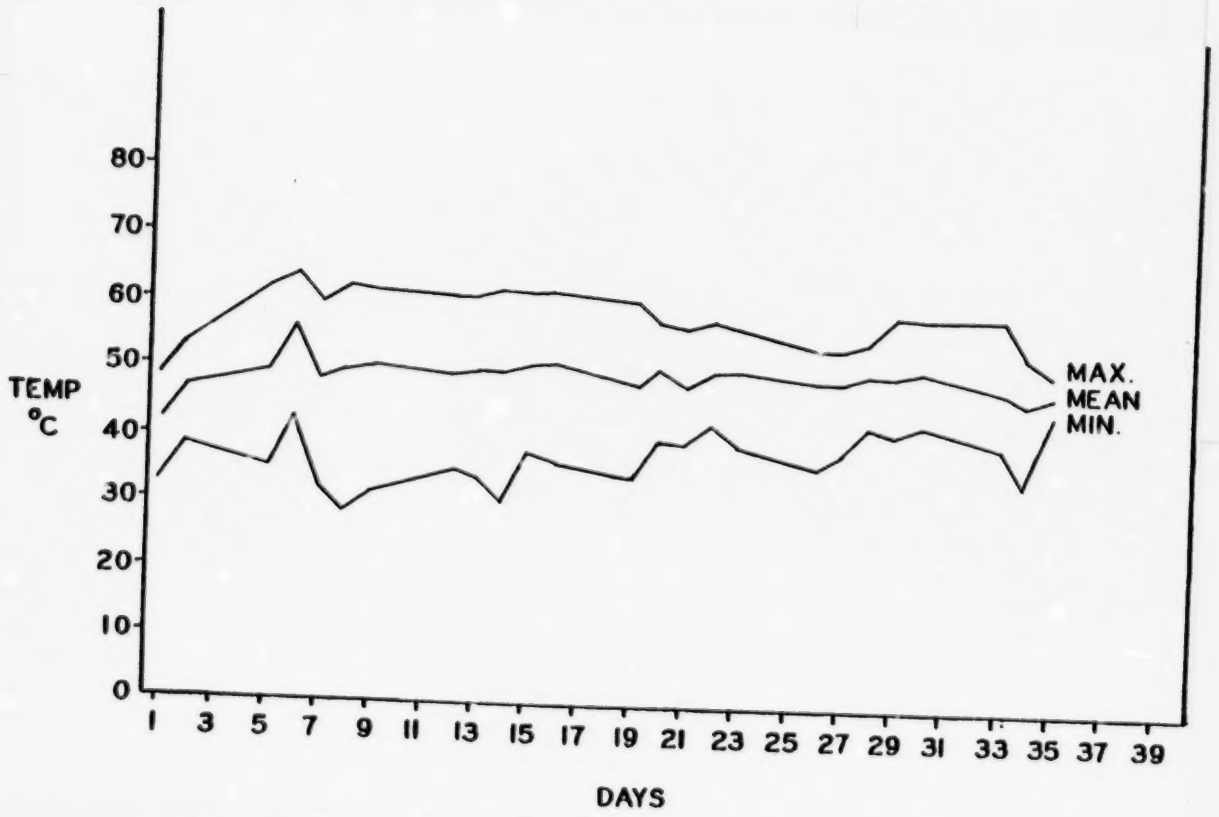


Figure 20. Temperature in Septage Compost Pile vs. Time
Location 4 - Depth 30 cm

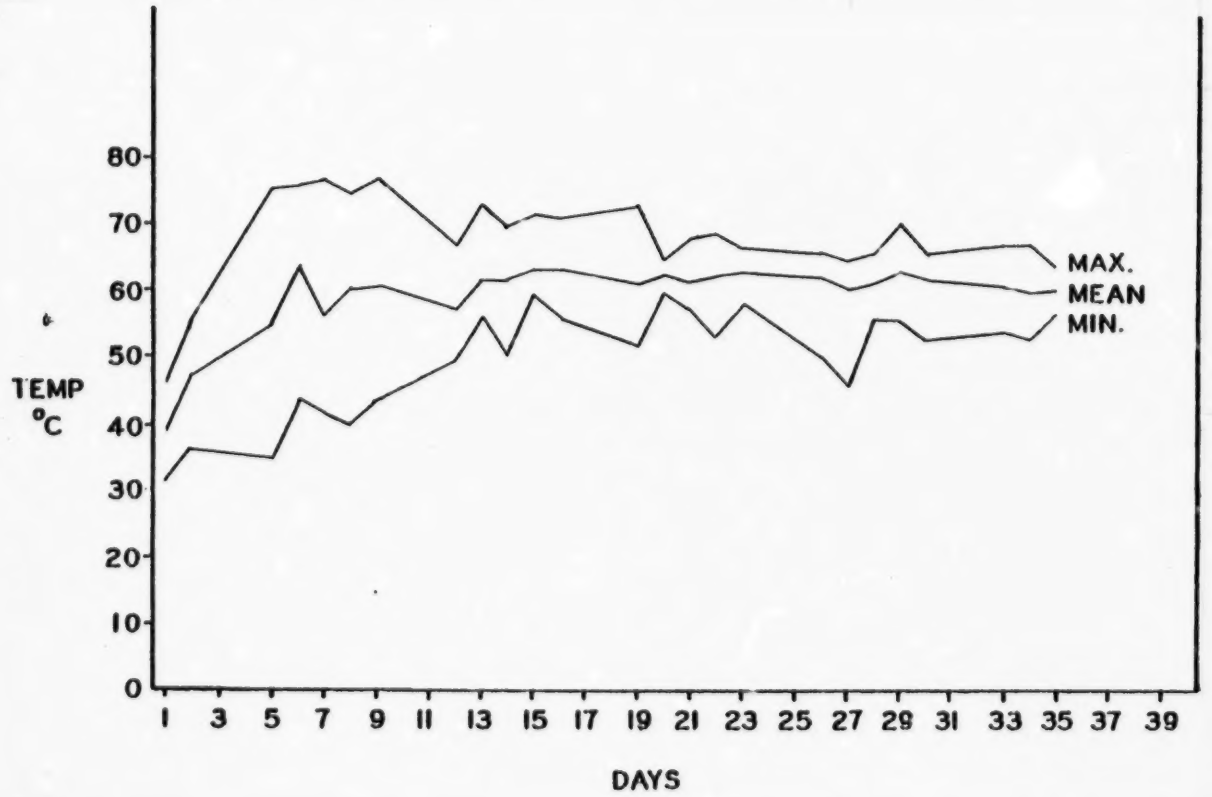


Figure 21. Temperature in Septage Compost Pile vs. Time
Location 4 - Depth 90 cm

SECTION 5

RESULTS AND DISCUSSION

This section is divided into two separate subsections for clarity and convenience: sanitary toilet waste composting and septage composting.

SANITARY TOILET WASTE COMPOSTING

Bulking Materials

A bulking material is any organic material which can be used within the static pile composting system to absorb liquids and provide suitable aeration porosity for proper composting of raw waste materials. Numerous materials can be used as bulking agents depending upon local availability. Ratios reported in this study may need to be varied due to local weather, available storage conditions, and bulking agent and waste characteristics. For example, if rainfall is abundant and storage is not under roof, some additional material may be required to absorb the liquid fractions of the waste. The reverse may be true for very dry conditions.

A total of 11,355 ℓ (3,000 gal) of sanitary waste was composted during the EPA funded project. Each mattress contained 5.4 cu m (7.1 cu yd) of compost. Woodchips were used directly over the perforated tubing to prevent clogging of the intake holes. Quantities of bulking materials for the "active" pile were: 7.4 cu m (9.7 cu yd) woodchips, 7.4 cu m (9.7 cu yd) sawdust, and 3.2 cu m (4.2 cu yd) compost per 3,785 ℓ (1,000 gal) of waste (Table 4). The blanket contained an average of 7.7 cu m (10.1 cu yd) of finished compost. At the C&O Canal, several organic materials have been successfully used as bulking agents. Sawdust, woodchips, leaves, and compost have been used successfully. More recently shredded paper "waste" generated from park headquarters has been used as a partial replacement for sawdust.

Characterization of Untreated Sanitary Toilet Waste

Laboratory analyses indicated a wide variation of BOD, COD, total coliforms, and fecal coliforms for raw wastes (Table 5). Variation was apparently due to several factors, including the length of time waste was held within the holding tanks of the toilet systems, the length of time in the holding tank at the compost site, and the inherent variability in the waste characteristics as generated.

TABLE 4

QUANTITIES OF BULKING MATERIALS USED FOR COMPOSTING OF SANITARY TOILET WASTE

Waste Volume	Mattress	Active Compost Pile			Blanket
		Woodchips	Sawdust	Old Compost	
	cu m	cu m	cu m	cu m	cu m
3,785	5.4	7.7	7.7	3.1	7.7
3,785	5.4	6.9	6.9	3.1	7.7
3,785	5.4	7.7	7.7	3.4	7.7

TABLE 5

SANITARY TOILET WASTE
CHARACTERIZATION

Parameter	Range		Mean	Std Dev	Samples
	Max	Min			
BOD, mg/ℓ	14,000	5,000	9,666.7	4,509.2	3
COD, mg/ℓ	35,000	29,000	32,666.7	3,214.6	3
Total Coliforms, MPN/g	2,400	39	827.3	1,362.0	3
Fecal Coliforms, MPN/g	2.400	<3	814.3	1,373.5	3
Salmonella, sp. (neg. or pos.)	neg.	neg.	--	--	3
Total Solids, %	2.8	2.1	2.5	0.36	3
Total Volatile Solids, % of total solids	71.4	34.6	52.8	18.4	3
pH	8.2	7.7	--	--	3
Soluble Salts, mg/ℓ	3,340	3,240	3,296.7	51.3	3
Total Kjeldahl Nitrogen, mg/ℓ	186,400	142,700	160,130	23,152.4	3
Total Phosphorus, mg/ℓ	6,190	3,329	4,493	1,503.1	3
Total Potassium, mg/ℓ	3,911	2,965	3,312.0	520.9	3
Cadmium, mg/ℓ	2.2	1.1	1.5	0.64	3
Copper, mg/ℓ	602	30	226	325.7	3
Lead, mg/ℓ	43	18	31	12.5	3
Nickel, mg/ℓ	8	6	7.3	1.2	3
Zinc*, mg/ℓ	757	173	406.7	309.0	3

* A disinfectant was used in these toilets which contained 67 mg/ zinc.

Data for Salmonella sp., total solids, and total volatile solids were more consistent with variation between samples less with septage (compare Tables 5 and 19).

Results of the chemical analyses of raw sanitary toilet waste were quite variable and characteristic of this type of material (Table 5). TKN values within the raw waste were quite high while the phosphorus and potassium levels were generally low. Metal concentrations were quite low with the exception of zinc. The moderate concentration of zinc in the raw sanitary toilet waste was believed to be due in part to the disinfectant used within individual toilet systems. Approximately 200 ml of this disinfectant containing 67 ppm zinc was added to each toilet during pumping-recharge operations.

Characterization of Sanitary Toilet Waste Composting

Samples taken from the various locations within the composting pile for evaluation of indicator organisms indicate that total coliform and fecal coliform levels dropped to less than three per gram between the second and third week of composting at all pile locations (Tables 6 and 7). By the third sampling cycle, and throughout the additional samplings, organism counts remained at these low levels.

Normally, during the take-down phase and stockpiling operation, there may be some reinoculation of organisms. However, the data indicated that either this incidence was low, or that the stockpile temperatures were such that these counts were quickly reduced after stockpiling, or both. Normally compost temperatures rise after the stockpiling operation and remain near or above 55°C for several weeks.

Salmonella sp. were detected only twice in 56 samplings during the active composting phase of this investigation, and not detected in subsequent samplings or in cured compost.

Analyses of the total solids alteration with composting time are presented in Table 8. Student - Newman - Keuls test (SNK*) results indicated (0.05 level) a significant increase in solids content (decrease in moisture content) with composting time, while the total volatile solids expressed as a percent of total solids remained unaltered with composting time (Table 9). pH of the raw sanitary toilet waste was high at 7.72 to 8.15. With composting time there appeared to be a drop in pH (Table 10). The pH of the finished compost ranged between 5.76 to 7.45.

Soluble salt content of sanitary toilet waste compost was quite high and remained at a high level throughout the composting cycle (Table 11). The final compost product appeared to retain this high soluble salt level, which may cause some management concerns with regard to product usability, particularly when used around salt sensitive plants.

*SNK is a mean separation test which is more conservative in its ability to detect differences among means than other mean separation tests. If differences are detected they are more likely to be real.

TABLE 6

SANITARY TOILET WASTE
TOTAL COLIFORM BACTERIA ALTERATION
WITH COMPOSTING TIME

MPN/g*

Composting Time	Range Max	Range Min	Mean	Std Dev	No. of Samples
Raw Waste 0 time	2,400	39	827	1,362.0	3
1 Week	750	<3	176	248.9	12
2 Weeks	43	<3	14	13.2	12
3 Weeks	4	<3	<3	0.4	12
4 Weeks**	<3	<3	<3	0.0	12
Compost 8 weeks	<3	<3	<3	0.0	8

* Samples incubated at 35°C.

** Active aerated composting occurred for 4 weeks, the piles were then dismantled and removed to a curing area.

TABLE 7

SANITARY TOILET WASTE
FECAL COLIFORM BACTERIA ALTERATION
WITH COMPOSTING TIME

MPN/g*

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples
Raw Waste 0 time	2,400	<3	814	1,373.5	3
1 Week	460	<3	63	142.2	12
2 Weeks	<3	<3	<3	0.0	12
3 Weeks	<3	<3	<3	0.0	12
4 Weeks**	<3	<3	<3	0.0	12
Compost 8 weeks	<3	<3	<3	0.0	18

* Samples incubated at 44.5°C

** Active aerated composting occurred for 4 weeks, the piles were then dismantled and removed to a curing area.

TABLE 8

SANITARY TOILET WASTE
TOTAL SOLIDS ALTERATION WITH COMPOSTING TIME

Percentage

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	2.8	2.1	2.5	0.36	3	
1 Week	57.8	39.2	45.8*	6.12	12	a
2 Weeks	53.3	36.2	44.2*	4.80	12	a
3 Weeks	54.2	44.5	49.9*	3.71	12	a
4 Weeks	61.1	39.9	51.1*	7.49	12	a
Compost 8 Weeks	59.3	47.1	53.5	4.26	8	a

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

* Analysis of variance significance at the 0.05 level.

TABLE 9

SANITARY TOILET WASTE
TOTAL VOLATILE SOLIDS ALTERATION WITH COMPOSTING TIME

Percentage of Total Solids

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	71.4	34.6	52.8	18.4	3	
1 Week	61.0	32.5	47.2 NS	7.65	12	a
2 Weeks	61.1	24.6	48.6 NS	9.71	12	a
3 Weeks	51.2	39.0	44.5 NS	3.56	12	a
4 Weeks	58.1	28.5	43.6 NS	9.72	12	a
Compost 8 Weeks	49.2	34.6	41.7	5.3	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Non-significant analysis of variance.

TABLE 10

SANITARY TOILET WASTE
pH ALTERATION WITH COMPOSTING TIME

Composting Time	Range		Number of Samples
	Max	Min	
Raw Waste 0 Time	8.15	7.70	3
1 Week	7.55	6.82	12
2 Weeks	7.72	6.56	12
3 Weeks	7.52	6.78	12
4 Weeks	7.31	5.80	12
Compost 8 Weeks	7.45	5.76	8

TABLE 11

SANITARY TOILET WASTE
SOLUBLE SALTS ALTERATION WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	3,340	3,240	3,297	51.3	3	
1 Week	2,200	850	1,261 NS	420.3	12	a
2 Weeks	2,700	700	1,592 NS	662.4	12	a
3 Weeks	1,540	820	1,433 NS	621.4	12	a
4 Weeks	2,450	800	1,346 NS	554.7	12	a
Compost 8 Weeks	2,500	880	1,598	634.2	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Non-significant analysis of variance.

TABLE 12

SANITARY TOILET WASTE
TOTAL PHOSPHORUS ALTERATION WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	6,190	3,329	4,493	1,503.1	3	
1 Week	3,328	1,994	2,770 NS	423.1	12	a
2 Weeks	3,261	2,138	2,712 NS	368.2	12	a
3 Weeks	3,008	2,225	2,631 NS	280.8	12	a
4 Weeks	3,495	2,173	2,858 NS	431.3	12	a
Compost 8 Weeks	3,765	2,267	2,871	624.8	12	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Non significant analysis of variance.

TABLE 13

SANITARY TOILET WASTE
TOTAL POTASSIUM ALTERATION WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	3,911	2,965	3,312	520.9	3	
1 Week	2,894	1,637	2,180 **	385.2	12	b
2 Weeks	7,565	1,380	3,114 **	1,836.5	12	ab
3 Weeks	3,854	1,174	2,359 **	846.8	12	b
4 Weeks	5,275	2,632	3,797 **	1,020.5	12	a
Compost 8 Weeks	4,012	1,774	2,694	692.9	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

** Analysis of variance, significance at the 0.01 level.

Phosphorus (P) and potassium (K) levels were quite low (Tables 12 and 13). These data indicate that the levels in the raw waste were low and that composting time had no significant effect upon P and K levels.

Total Kjeldahl nitrogen (TKN), ammonium (NH_4) and nitrate-nitrite nitrogen (NO_3-NO_2) data are summarized in Tables 14, 15, and 16. Nitrogen data were quite variable, but indicate that sanitary toilet waste does contain somewhat higher concentrations of nitrogen than does septage.

TKN content in the raw sanitary toilet waste was approximately 16 percent by weight of dry solids (Table 14). In the final compost TKN content was 1.1 percent by weight of dry solids. This initial high level is apparently a result of the nature of the waste and its presence within a closed vessel without flow through the system as occurs with septic systems. Analysis of variance conducted on the mean values during the 4 weeks composting detected no significant alteration in TKN concentration with composting time.

Nitrate-nitrite nitrogen levels within the sanitary toilet waste compost were relatively low (Table 15). Analysis of variance of these values with composting time did not detect any significant difference between means. Student - Newman - Keuls mean separation test for significance did detect differences. Calculation of the correlation coefficient for NO_3-NO_2 alteration with time indicates a low coefficient of correlation of $r = -0.11$. This coefficient reflects two data points which appear to be unusually high 107 ug/g and 32 ug/g (both data points were detected during week 2 of composting in different compost runs); the range for the remaining ten observations was 1.03 ug/g to 3.72 ug/g (Refer to Table 15). Because of the rapidity of nitrogen alteration within the composting medium, duplicate laboratory analyses of these suspicious data observations were unable to be performed.

However, analysis of variance of ammonium levels with composting time for sanitary compost did not detect any significant differences. The SNK mean separation test did not detect differences with composting time.

Concentrations of five heavy metals were recorded throughout the length of the project and are summarized in Table 17. The five metals analyzed were cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn). The overall level of any of these metals was low principally due to the nature of the waste materials treated. Human wastes were relatively free of metal contamination. The only incidence of somewhat elevated metal loading was noted with zinc. Since installation of the sanitary toilets, a zinc based disinfectant-deodorizer has been used in the recharging of the toilets after pumping. About 200 ml of the disinfectant-deodorizer is placed into the toilet tank with a recharge of 19 ℓ (about 5 gal) of water after each pumping operation. This recharge was a partial explanation of the moderate zinc level in the compost. It has been recommended that the C&O Canal phase out the use of this disinfectant-deodorizer and begin utilizing formaldehyde as the sole disinfectant. New formaldehyde formulations have been successfully used by the U.S. Forest Service. Formaldehyde, by its chemical nature, would be completely degraded within the composting system yielding a safer compost product (personal communication with U.S. Forest Service). Although this present

TABLE 14

SANITARY TOILET WASTE
TOTAL KJELDAHL NITROGEN ALTERATION WITH
COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	186,400	142,700	160,130	23,152.4	3	
1 Week	8,100	5,060	6,583 NS	912.8	12	a
2 Weeks	9,680	6,030	7,782 NS	1,406.1	12	a
3 Weeks	12,820	5,000	8,143 NS	2,864.1	12	a
4 Weeks	9,730	5,510	7,708 NS	1,488.6	12	a
Compost 8 Weeks	23,580	6,400	11,021	6,031.0	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Non significant analysis of variance.

TABLE 15

SANITARY TOILET WASTE
NITRATE AND NITRITE NITROGEN ALTERATION WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	--	--	--	--	--	
1 Week	8	0	2.2 NS	2.5	12	c
2 Weeks	107	1	14.9 NS	30.3	12	a
3 Weeks	12	0	3.8 NS	3.4	12	b
4 Weeks	16	0	4.2 NS	4.5	12	b
Compost 8 Weeks	3	0	1.9	1.0	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Non significant analysis of variance.

TABLE 16

SANITARY TOILET WASTE
AMMONIUM ALTERATION WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	--	--	--	--	--	
1 Week	1,519	746	1,084 NS	254.0	12	a
2 Weeks	1,536	708	974 NS	332.6	12	a
3 Weeks	1,790	445	1,007 NS	428.1	12	a
4 Weeks	1,657	566	969 NS	410.8	12	a
Compost 8 Weeks	1,826	18	885	646.2	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Non significant analysis of variance.

TABLE 17

SANITARY TOILET WASTE
HEAVY METAL CHARACTERISTICS OF
RAW WASTE AND COMPOST

ug/g

Metal	Material	Range Max	Range Min	Mean	Standard Deviation	Number of Samples
Cd	0 Time Waste	2.2	1.1	1.5	0.6	3
	Compost*	3.4	1.5	2.6	0.5	48
	Compost 8 Weeks	3.2	2.8	3.0	0.13	8
Cu	0 Time Waste	602	30	226	325.7	3
	Compost*	61	29	43.6	8.9	48
	Compost 8 Weeks	61	44	50	5.9	8
Pb	0 Time Waste	43	18	31	12.5	3
	Compost*	72	31	52.9	13.4	48
	Compost 8 Weeks	88	62	73	7.7	8
Ni	0 Time Waste	8	6	7	1.2	3
	Compost*	34	16	25.4	6.6	48
	Compost 8 Weeks	34	22	28	3.7	8

TABLE 17 (Continued)

SANITARY TOILET WASTE
HEAVY METAL CHARACTERISTICS OF
RAW WASTE AND COMPOST

ug/g

Metal	Material	Range Max	Range Min	Mean	Standard Deviation	Number of Samples
Zn	0 Time Waste	757	173	407	309.0	3
	Compost*	223	129	187.4	20.9	48
	Compost 8 Weeks	247	189	217	16.8	8

* These data represent the mean value for heavy metals assayed during the 4 weeks of active composting.

zinc loading was not considered to be excessive, it could pose a potential problem which could easily be avoided.

As expected, the lowest temperature readings were within the blanket rather than within the active composting medium. This low temperature condition would be expected around the lower sections of the pile due to sloughing of the blanket materials and active air movement around the pipe. The piles were approximately 2.7 m (9 ft) high when constructed and generally settled to approximately 1.8 m (7 ft).

Mean temperature values for the 90 cm depth in the pile exceeded the desired 55°C temperature within 2 to 5 days after setup at most locations and usually were above 55°C for extended periods. Temperatures above 55°C have been maintained for periods of 6 to 7 weeks.

Temperatures were generally higher at the top of the pile and in the central core. Lowest temperatures were experienced around the perimeter of the pile just beneath the blanket, and in the bottom of the pile near the tubing. These conditions are thought to result from the greater air movement resulting in the heat loss experienced at these locations.

Although oxygen data recorded were extensive, no data are presented. It was a common observation that composting activity proceeded well when an oxygen percentage of 5 - 15 percent was maintained within the active composting pile. This percentage varied widely within the pile. The highest levels of oxygen were realized near the blanket - compost interface and near the tubing. The lowest levels were generally found in the core and at the top of the composting pile. The preferred range for oxygen levels appeared to be between 8 and 10 percent; however, it was difficult to maintain precise oxygen percentages at all locations, and variability was common.

Rainfall tends to affect the oxygen - temperature relationship within the pile. Rainfall and maximum - minimum temperatures were recorded daily at the site. However, these data cannot be averaged over the composting season. During the composting activities, occasional rainfall of 5 cm (about 2 in) or greater was experienced. Within the composting medium the temperature may be reduced by 1 to 5° C depending upon the amount of rainfall and location of temperature recordings within the pile. This drop was generally a short lived phenomenon. It was felt that a minimum of 3 weeks of active composting was a desirable exposure time for a reasonable pathogen kill. Longer periods could be maintained if desired. C&O Canal activities were such that some compost piles remained standing for up to 8 weeks or more depending upon management needs at the site. Generally, active compost piles were maintained for a period of 4 weeks to ensure a pathogenically safe end product. This phase was followed by 3 to 6 months of stockpiling prior to utilization of the product.

SEPTAGE COMPOSTING

Bulking Materials

During this project, the septage hauler was instructed to provide only domestic septage, preferably each load from a single household. The first compost pile constructed using only septage did not perform as anticipated. Temperatures were generally lower and the oxygen percentages quite variable. Piles two and three maintained consistently higher, more desirable temperature and oxygen ranges. The second and third piles functioned routinely after some alterations were made to the static pile configuration. The first alteration was to increase the blanket thickness by 15 cm to ensure proper insulation of the composting mixture while maintaining blanket porosity. By increasing blanket thickness, and allowing the damper to remain open for a longer period of time, heat was retained within the composting mixture while simultaneously increasing the oxygen drawn through the pile. These modifications achieved proper composting temperatures.

Table 18 summarizes the bulking materials used to build each individual compost pile. The relative degree of wetness of these materials may necessitate using more or less material to absorb the liquid fractions of the waste. The amount of septage composted averaged 4,000 ℓ (1,067 gal) per setup with a ratio of bulking materials of 7.4 cu m (9.7 cu yd) woodchips, 7.4 cu m (9.7 cu yd) sawdust, and 3.2 cu m (4.2 cu yd) compost. About 5.4 cu m of compost was used as the mattress material and 11.7 cu m of compost used as blanket materials for the three compost piles. It would be more realistic to use 13.8 cu m to reflect the increase in thickness as the average for the blanket material, since the first pile did not function as effectively as the latter two.

As with sanitary waste composting, woodchips were placed immediately over the oval of perforated tubing on the mattress to prevent clogging of the intake holes of the tubing.

Characterization of Septage

Septage samples were taken in the same manner as the sanitary toilet waste samples. Samples were split with half of the sample taken to a commerical laboratory and half to the ESL for analytical determinations.

Analysis of the data revealed wide variations in BOD, COD, and total solids for septage samples. Total coliforms and fecal coliforms were highly variable between the three sampling times. Salmonella sp. was not found in the raw waste (Table 19).

Total solids and total volatile solids were somewhat lower for septage than for sanitary toilet waste (compare Tables 5 and 19).

TABLE 18

BULKING MATERIALS USED FOR
COMPOSTING SEPTAGE

Waste	Mattress Compost	Active Compost Pile			Blanket Compost
		Woodchips	Sawdust	Old Compost	
ℓ	cu m	cu m	cu m	cu m	cu m
4,731	5.4	7.7	7.7	3.1	7.7
3,785	5.4	6.9	6.9	3.1	15.3
3,785	5.4	7.7	7.7	3.4	12.2

TABLE 19

SEPTAGE CHARACTERIZATION

Parameter	Range		Mean	Standard Deviation	Number of Samples
	Max	Min			
BOD, mg/ℓ	3,300	2,700	2,933	321.5	3
COD, mg/ℓ	26,000	4,300	15,100	10,850.3	3
Total Coliforms, MPN/g	>11,000	<3	3,748	6,281.8	3
Fecal Coliforms, MPN/g	4,600	<3	1,571	2,623.7	3
Salmonella, sp. (neg. or pos.)	neg.	neg.	--	--	3
Total Solids, %	2.4	1.1	1.7	0.6	3
Total Volatile Solids, % of total solids	72.7	41.2	58.8	15.8	3
pH	6.5	5.9	--	--	3
Soluble Salts, mg/ℓ	525	135	278.3	214.6	3
Total Kjeldahl Nitrogen, mg/ℓ	22,960	6,720	13,293	8,550.5	3
Total Phosphorus, mg/ℓ	5,495	1,615	2,982.7	2,178.6	3
Total Potassium, mg/ℓ	305.0	80.5	158.5	127.0	3
Cadmium, mg/ℓ	2.3	1.5	1.8	0.5	3
Copper, mg/ℓ	827	40	516.3	418.8	3
Lead, mg/ℓ	103	33	62.7	36.2	3
Nickel, mg/ℓ	16	9	12.3	3.5	3
Zinc, mg/ℓ	649	214	418.7	218.6	3

Analyses of the chemistry of the septage indicated that the pH was lower than sanitary toilet waste. Soluble salts, TKN, total phosphorus and total potassium were all considerably lower than the levels observed for sanitary waste (compare Tables 5 and 19).

Heavy metal content of septage was higher than for sanitary toilet waste by a factor of nearly two. The greater metal concentrations may have been due to contributions from household products containing heavy metals, many of which may be retained in the septic tank.

Characterization of Septage Composting

Analysis of indicator organism concentrations indicated that the maximum total coliform count did not fall to less than 3 per gram during the composting period, as was the case with sanitary toilet waste (Tables 6 and 20). Further scrutiny of the raw data indicated that the maximum counts displayed in Table 20 are from the first compost pile that did not achieve the desired composting temperature range. Data collected from the second and third piles indicated that when proper compost temperatures were achieved, the maximum level of total coliforms dropped to less than 3 per gram between the second and third week of composting for all sampling locations.

Fecal coliform levels were reduced to less than 3 per gram by the second week for all three piles. Counts for both total coliforms and fecal coliforms did not increase when the compost piles were taken down and moved to the storage site for an additional 4 weeks of curing (Table 21).

The presence or absence of Salmonella sp. was determined and the results indicated that the organism was present in only 2 of 56 septage compost samples taken. These positive determinations were detected once each during the first and second week of composting in the first septage compost pile. None were detected in the second and third piles.

Total solids significantly increased with composting time at the 0.01 level of significance (Table 22). Mean separation tests detected a significant difference between the second and third weeks of composting. This increase is probably a result of moisture loss during the composting process. Total volatile solids, as a percent of total solids, were unaltered by the composting activity (Table 23).

pH alterations with composting time for the septage did not appear to change (Table 24). The pH of the final compost ranged from 6.3 to 7.3.

Analysis of variance for soluble salts content was significant at the 0.01 level; however, the mean separation tests did not detect any significant difference between means (Table 25). Soluble salt content of composted material was generally high but tends to be reduced with stockpiling of the mixtures, particularly over the period of 6 months to a year (21).

Analysis of total phosphorus and total potassium were low (Table 26 and 27) when compared to levels in commercial fertilizers. Total potassium

TABLE 20

SEPTAGE
TOTAL COLIFORM BACTERIA ALTERATION
WITH COMPOSTING TIME

MPN/g*

Composting Time	Range		Mean	Standard Deviation	Number of Samples
	Max	Min			
Raw Waste 0 Time	>11,000	<3	3,749	6,281.8	3
1 Week	≥24,000	4	2,075	6,905.4	12
2 Weeks	93	<3	18	25.3	12
3 Weeks	23	<3	5	5.8	12
4 Weeks	23	<3	6	5.9	12
Compost 8 Weeks	<3	<3	<3	0.0	8

* Samples incubated at 35°C.

TABLE 21

SEPTAGE FECAL COLIFORM BACTERIA ALTERATION
WITH COMPOSTING TIME

MPN/g*

Composting Time	Range		Mean	Standard Deviation	Number of Samples
	Max	Min			
Raw Waste 0 Time	4,600	<3	1,575	2,623.7	3
1 Week	11,000	<3	931	3,171.1	12
2 Weeks	<3	<3	<3	0.0	12
3 Weeks	<3	<3	<3	0.0	12
4 Weeks	<3	<3	<3	0.0	12
Compost 8 Weeks	<3	<3	<3	0.0	8

* Samples incubated at 44.5°C.

TABLE 22

SEPTAGE TOTAL SOLIDS ALTERATION WITH COMPOSTING TIME

Percentage

Composting Time	Range Max	Range Min	Mean	Moisture	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	2.4	1.1	1.7	98.3	0.65	3	
1 Week	54.1	37.0	44.8	55.2**	5.82	12	b
2 Weeks	55.2	32.8	45.3	54.7**	6.77	12	b
3 Weeks	63.9	42.5	52.5	47.5**	7.20	12	a
4 Weeks	68.8	44.1	55.4	44.6**	7.66	12	a
Compost 8 Weeks	60.8	40.3	49.4	50.8	7.22	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

** Analysis of variance, significance at the 0.01 level.

TABLE 23

SEPTAGE
TOTAL VOLATILE SOLIDS ALTERATION WITH COMPOSTING TIME

Percentage of Total Solids

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	72.7	41.2	58.8	16.07	3	
1 Week	60.6	34.3	46.2 NS	8.23	12	a
2 Weeks	54.5	27.7	44.9 NS	7.26	12	a
3 Weeks	52.1	31.5	44.0 NS	5.89	12	a
4 Weeks	48.6	29.7	39.7 NS	5.84	12	a
Compost 8 Weeks	55.4	40.1	48.9	6.05	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Nonsignificant analysis of variance.

TABLE 24

SEPTAGE pH ALTERATION WITH COMPOSTING TIME

Sampling Interval	Range		Number of Samples
	Max	Min	
Raw Waste 0 Time	6.50	5.87	3
1 Week	7.65	6.78	12
2 Weeks	7.52	6.79	12
3 Weeks	7.22	6.99	12
4 Weeks	7.38	6.72	12
Compost 8 Weeks	7.35	6.34	8

TABLE 25

SEPTAGE SOLUBLE SALTS ALTERATION
WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	525	135	278	214.6	3	
1 Week	920	560	728**	107.1	12	a
2 Weeks	1,200	<500	792**	253.9	12	a
3 Weeks	1,200	<500	703**	228.6	12	a
4 Weeks	1,400	<500	801**	279.7	12	a
Compost 8 Weeks	1,370	600	880	275.8	8	

†SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

** Analysis of variance, significance at the 0.01 level.

TABLE 26

SEPTAGE TOTAL PHOSPHORUS ALTERATION
WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	5,495	1,615	2,983	2,178.6	3	
1 Week	3,228	1,557	2,247 NS	590.3	12	a
2 Weeks	3,193	1,609	2,245 NS	473.7	12	a
3 Weeks	3,067	1,732	2,231 NS	525.6	12	a
4 Weeks	2,842	1,857	2,224 NS	366.1	12	a
Compost 8 Weeks	2,894	2,115	2,460	246.7	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Nonsignificant analysis of variance.

TABLE 27

SEPTAGE TOTAL POTASSIUM ALTERATION WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	305	80	158.5	127.0	3	
1 Week	2,792	985	1,644.8 NS	505.8	12	a
2 Weeks	7,019	1,024	2,370.8 NS	1,589.6	12	a
3 Weeks	2,745	1,367	2,102.4 NS	479.5	12	a
4 Weeks	3,987	1,150	2,214.8 NS	874.43	12	a
Compost 8 Weeks	3,673	1,409	2,092.0	782.0	8	

† SNK Letters within column which are the same were not statistically different by Student - Neuman - Keuls mean separation at the 0.05 level.

NS Non significant analysis of variance.

TABLE 28

SEPTAGE TOTAL KJELDAHL NITROGEN ALTERATION
WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	22,960	6,720	13,293	8,550.5	3	
1 Week	7,900	4,120	5,861 NS	1,211.7	12	a
2 Weeks	7,750	3,700	5,538 NS	983.9	12	a
3 Weeks	13,750	4,220	6,421 NS	2,657.2	12	a
4 Weeks	7,140	3,220	5,274 NS	1,177.0	12	a
Compost 8 Weeks	11,640	5,030	6,939	2,073.0	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Nonsignificant analysis of variance.

levels within the septage compost are similar to those levels found in the USDA sewage sludge compost (14). Neither total phosphorus nor total potassium concentrations showed any significant change in composting.

Total Kjeldahl nitrogen (TKN) values in septage (Table 28) and the final compost product appear to be somewhat lower than those of sanitary toilet wastes. Raw septage contained 1.3 percent TKN while the final compost product contained 0.7 percent TKN.

Analysis of variance for alteration of TKN with compost time did not detect any significant difference during active composting. Similarly, SNK mean separation tests did not yield any significant difference.

Nitrate-nitrite nitrogen levels within the composting mixture were relatively low (Table 29). Analysis of variance and SNK mean separation tests detected no significant difference during active composting.

Ammonium levels (Table 30) within septage compost appeared to be much lower than the corresponding levels within sanitary toilet waste compost, perhaps owing to inherent differences between the raw wastes. Analysis of variance and SNK mean separation tests did not detect any significant differences during the composting event.

Analyses of heavy metals in septage compost indicated some variability; however, metal levels in the compost were generally low (Table 31). Analysis of variance and the mean separation tests did not indicate any significant difference with composting time.

The compost pile temperatures for septage were generally lower than the corresponding values for sanitary toilet waste. The first septage pile constructed did not achieve acceptable composting temperatures (55°C) at all locations (refer to Figure 5 for definition of monitoring locations). In nearly every case, the minimum line on the graph represents data points obtained from the first septage compost pile. Prior to the second and third compost trials the insulation blanket thickness was increased from 30 to 45 centimeters and the amount of oxygen drawn through the piles was increased. To achieve the increased flow, the damper was allowed to remain open for a longer period and the blower was set to run for 8 to 10 minutes per 20 minute time interval. Consequently, the second and third septage piles achieved desired temperature levels (Figures 14 through 21). These same general trends were observed to occur with the oxygen content of the piles.

TABLE 29

SEPTAGE NITRATE AND NITRITE NITROGEN ALTERATION WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	--	--	--	--	--	--
1 Week	13	0	2.3 NS	3.7	12	a
2 Weeks	6	1	3.1 NS	1.5	12	a
3 Weeks	9	0	1.2 NS	2.6	12	a
4 Weeks	3	0	0.9 NS	1.1	12	a
Compost 8 Weeks	15.1	0.3	2.8	5.0	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Nonsignificant analysis of variance.

TABLE 30

SEPTAGE AMMONIUM ALTERATION WITH COMPOSTING TIME

ug/g

Composting Time	Range Max	Range Min	Mean	Standard Deviation	Number of Samples	SNK†
Raw Waste 0 Time	--	--	--	--	--	--
1 Week	117	5	47.6 NS	35.3	12	a
2 Weeks	44	9	24.7 NS	12.3	12	a
3 Weeks	152	15	56.7 NS	42.8	12	a
4 Weeks	173	4	59.5 NS	54.8	12	a
Compost 8 Weeks	202	32	120.8	66.4	8	

† SNK Letters within column which are the same were not statistically different by Student - Newman - Keuls mean separation at the 0.05 level.

NS Nonsignificant analysis of variance.

TABLE 31

SEPTAGE HEAVY METAL CHARACTERISTICS OF RAW WASTE AND COMPOST TIME

ug/g

Metal	Material	Range Max	Range Min	Mean	Standard Deviation	Number of Samples
Cd	0 Time Raw Waste	2.3	1.5	1.8	0.5	3
	Compost *	4.0	1.6	2.4	0.5	48
	Compost 8 Weeks	3.2	1.1	2.5	0.7	8
Cu	0 Time Raw Waste	827	40	516	418.8	3
	Compost *	314	30	83.0	69.4	48
	Compost 8 Weeks	214	54	91	74.4	8
Pb	0 Time Raw Waste	103	33	63	36.2	3
	Compost *	66	32	47.5	8.5	48
	Compost 8 Weeks	75	46	59	12.1	8
Ni	0 Time Raw Waste	16	9	12	3.5	3
	Compost *	35	9	21.8	6.2	48
	Compost 8 Weeks	38	19	26.5	7.4	8

TABLE 31 (Continued)

SEPTAGE HEAVY METAL CHARACTERISTICS OF RAW WASTE AND COMPOST TIME

ug/g

Metal	Material	Range		Mean	Standard Deviation	Number of Samples
		Max	Min			
Zn	0 Time Raw Waste	649	214	419	218.6	3
	Compost *	240	122	165.5	30.4	48
	Compost 8 Weeks	242	149	190	39.4	8

* These data represent the mean value for heavy metals assayed during 4 weeks of active composting.

SECTION 6

ECONOMIC ANALYSIS

The basis of the economic analysis was C&O Canal records for the period of the EPA grant, July 12, 1978 to July 12, 1979. Costs were categorized as capital costs, labor costs, materials and utilities costs, administrative costs, summary costs, and value of product.

The unit costs for composting of relatively small volumes of liquid waste are high. However, it is important to mention that composting renders the responsible agency independent with regard to their waste treatment needs. There are no expensive structures to erect; sites can be as bland or elaborate as desired depending upon economics; there are no permanent personnel "on duty" at the site, their presence is required only during periodic monitoring and composting activities; the system effectively transforms a very offensive waste into a valued resource; and other "wastes," i.e., office paper waste and similar organics, can be blended into the composting system.

Capital Cost

These costs have been divided into three areas: land, site development, and equipment purchase (Table 32). These costs were incurred in 1976.

Land

The National Park Service has acquired land tracts adjacent to the C&O Canal for inclusion in the park. The Land Acquisition Program was the means by which the land at the compost site was acquired. The site chosen was segregated from proposed development and yet was easily accessible for the maintenance staff. Since there was no charge assessed for site acquisition under this program, cost of land was not included in this analysis.

Site Development

Site development costs include those costs attributable to development of ½ mile of road; grading of the site including a diversion ditch and oversized holding basin for onsite runoff; bulking material storage including acquisition of these materials; the purchase of bluestone for the roadway and pad surfacing; grass seed; and installation of electrical service.

TABLE 32

CAPITAL COSTS OF COMPOSTING OPERATION
(1976 Costs)
AT THE C&O CANAL

Item	Cost
Land (acquired through Land Acquisition Program)	$ 0.00
Site Development	
Labor	$1,951.31
Rental Equipment	4,436.50
Crushed Stone	1,545.00
Grass Seed	100.00
Electrical Services	555.85
	$8,588.66
Equipment Purchase for Composting	
Blowers. timer	$ 193.64
Tractor Restoration	257.78
Thermometers $32.50 x 4 ea.	130.00
	$ 581.42

Equipment Purchase

Equipment purchase included two blower systems (timeclock, motor and blower; one set was to act as an emergency backup), restoration of a front end loader, and the purchase of monitoring equipment.

Labor Costs

Tree trimming and cleanup maintains clearances at activity sites and creates a source of woodchips for use as bulking materials (Table 33). Maintenance involved with equipment is generally minimal owing to the few pieces involved at the site. The tractor, simply because of age, required the most attention. To date, preventive maintenance has been a key to holding down equipment maintenance costs.

Labor costs were calculated on a man year basis and were relatively low. Personnel responsible for composting operations handle much of the bulking material acquisition and transport - stockpiling activities at the site as well as site cleanliness. Personnel activities along the towpath involve, in addition to toilet maintenance and pumping activities, trash pickup, mowing, firewood supply to campgrounds, etc.

Materials and Utilities Costs

These costs were divided into four major headings: obtaining organic bulking materials, miscellaneous supplies, equipment rental, and utility charges (Table 34).

Organic Bulking Materials

Organic bulking material acquisition was generally performed through routine maintenance activities. For example, if there was storm damage or general tree trimming activities required along the Canal, the limbs and brush were routinely chipped and hauled to the compost site at the end of the working day or as necessary. Leaves were collected during general fall cleanup activities around visitor and office complexes and transported to the compost site. Sawdust was purchased from local suppliers and transported to the site. Sawdust acquisition was labor intensive and required about 2 days to complete. Practice had been to use small volume C&O Canal trucks rather than large volume vehicles. The recommendation has been made to use large volume trucks, which will reduce this cost in the future. C&O Canal since 1978 has been shredding their office paper and substituting shredded paper for sawdust. Some sawdust is still used.

Another alternative which should be considered at any compost site to maintain efficiency is the use of a roof over the organic storage and composting pad. This would be especially desirable in areas of high rainfall. Protection of both organics and the composting pile from the elements would ensure maximum absorption of liquids at pile setup and protection against saturation of the piles during composting.

TABLE 33

ANNUAL LABOR COSTS OF
COMPOST OPERATION

Operating Costs	
Labor to Maintain Site:	
Trim Road Overhang	
.25 MD @ $65.00/day	$ 16.25
Equipment Maintenance (max. est. includes loader, blowers, etc.)	$ 100.00
	$ 116.25
Labor to Operate Site	
To operate site and obtain bulking organics	
24 MD @ $65.00/day	$1,560.00
2 man months to pump and clean toilets, trash pickup, firewood supply, etc. (these activities done routinely whether composting or not).	
24 MD/month x $65.00 x 2 months	3,120.00
	$4,680.00
	$4,796.25

TABLE 34

ANNUAL MATERIALS AND UTILITY COSTS FOR COMPOST OPERATION

(Supplies and Materials)

Organic Bulking Materials

Sawdust (40 loads) $3/cu yd x 123 yds	$ 369.00
Woodchips (30 loads) $5/cu yd x 121 yds	605.00
Leaves (10 loads) free x 40 cu yds (collected anyway)	NC
Compost - site generated	NC
	$ 974.00

Miscellaneous Supplies

PVC piping 2 rolls/yr x $60.00	$ 120.00
PVC "T"s 6 ($1.00 ea x 6/yr)	6.00
Duct Tape 4 ($4.00/roll)	16.00
Agricultural limestone 6 bags @ $3.00 ea	18.00
Bluestone @ $3/ton; 21 ton/yr	63.00
	$ 223.00

Rental Equipment

Tractor-loader 20 MD/yr @ $8 hr (160 hours x $8) (used to obtain organics and for operations)	$1.280.00
Dump truck $16.00/hr (14 days)	$1,792.00
	$3,072.00

Utility Charge (Electricity)

592 Kilowatt hours/year @ 12.3¢/Kwh	$ 72.82

Miscellaneous Supplies

Supplies are replenished annually and include the purchase of both perforated and solid corrugated polyethylene tubing. This tubing is reused whenever feasible; however, the perforated tubing which is placed in the mattress is not recovered. "Ts" and "Ys" used to connect the perforated tubing to the solid tubing are reused as are the similar "Ts" and "Ys" used along the connector tubing. Connector tubing has been in use continually since 1976.

Duct tape is a disposable commodity and replenished as needed. It is used to seal any joints along the tubing.

Finely ground agricultural limestone is replenished as necessary. It is distributed over the site upon completion of any single day's mixing activities to maintain site cleanliness, proper soil pH, and reduce odors.

Rental Equipment

Replenishment of bulking organics is a routine maintenance activity as mentioned above. These costs reflect the rental costs incurred through the use of vehicles in support of the composting activities. At present, this acquisition is capital intensive owing to the use of relatively small haul vehicles. Larger vehicles or bulk replenishment would reduce these costs.

Utility Charges

The electricity charges are paid at a flat yearly rate of $72.82 (12.3¢/kwh). To date no additional charges have been incurred. An alternative to these utility charges would be the installation of either a solar collection or wind generating system along with appropriate storage batteries. These alternatives may be desirable for back-country use where utilities are nonexistent.

Administrative Costs

Administrative costs associated with compost site management are quite low. These costs reflect coordination efforts with maintenance staff to obtain supplies and materials, paperwork and personnel matters, visitation to the site by outside parties, etc. About 10 man days per year are dedicated to these activities at a daily cost of $45, or $450 for the year's administrative activities.

Summary Costs

Table 35 presents a summary of the total annual costs to treat the waste material generated along the C&O Canal during the EPA project period. During any single season, the quantity of waste generated will vary depending upon visitation to the park. However, during the period of this project, it cost the C&O Canal National Historical Park about $0.60/gal. to treat approximately 12,500 gallons of material generated (Table 35).

TABLE 35

SUMMARY OF ANNUAL COSTS OF
COMPOSTING LIQUID WASTES

Site Maintenance	$ 116.25
Labor	1,560.00
Organic Bulking Materials	974.00
Miscellaneous Supplies	223.00
Rental Equipment	3,072.00
Utilities (electric)	72.82
Administrative Costs	450.00
Total Cost To Treat Waste for 1 Year	$6.468.07
Amortization of Capital at 7 1/8 Percent for 20 Years	$ 874.08

Total Annual Cost Per Gal

$$\frac{\$6,468.07 + 874.08}{12,250 \text{ gal}} = \$0.599/\text{gal}$$

This cost seems excessive. However, when given the alternatives of construction of a conventional treatment facility or perhaps modification of the toilet systems to reduce or eliminate pumping, the cost is quite respectable.

Product Values

The compost product has a value which can be compared with the organic materials produced by local suppliers (Table 36). In the Washington, DC area composted products are available for purchase from various suppliers. Retail cost of a product similar to that generated from the National Park Service operations is $15.00 per cubic yard. The C&O Canal generated 300 cubic yards of compost during the 1978 product, which at this rate would have a value of $4,500. If the dollar value of the composted material is subtracted from the the total annual cost, the net cost to "treat" one gallon of waste can be recalculated to be $0.23 per gallon.

TABLE 36

PRODUCT VALUE OF COMPOST

Compost values * - $10 - $20/cubic yard
Peat Moss * - $27 - $78/cubic yard

	Cost Cu yd	Compost Product cu yd	Value of Product
	Dollars		
Compost	10	300	$ 3,000
	20	300	6,000
Peat Moss	27	300	8,100
	78	300	23,400

* Values of composts and peat moss products are based upon quoted costs from local suppliers. Composts are of similar nature to the sanitary waste and septage compost products generated at the C&O Canal site.

Peat moss quotes were supplied by several nurseries and/or garden suppliers. These materials are commonly used within the horticultural and landscaping trades. The large difference between quotes is due principally to how the material is delivered, i.e., bulk vs. bagged.

SECTION 7

REFERENCES

1. Anon. Environmental Assessment of Compost Project Within The Chesapeake and Ohio Canal National Historical Park Near Dargan, Maryland. U.S. Dept. of Interior, NPS, NCR/L 7617 - (PEL), Washington, DC, 1976.

2. Anon. First Progress Report: Static Pile Composting of Wastewater Sludge. USEPA Technology Transfer Capsule Report EPA-625/2-77-014, 1977.

3. Anon. Summary of Data, Analyses of Waste from Vault Toilets. U.S. Forest Service, Shoshone National Forest, Cody, WY.

4. Black, C. A., et al. (ed). Methods of Soil Analyses, Part 2, Chemical and Microbiological Properties. Agronomy No. 9, American Society of Agronomy, Madison, WI., 1965. 1572 pp.

5. Bowker, R. P. G. Treatment and Disposal of Septic Tank Sludges - A Status Report. USEPA MERL-WRD, Cincinnati, OH. May, 1977. 50 pp.

6. Colacicco, D, E. Epstein, G. B. Willson, J. F. Parr, and L. A. Christensen. Costs of Sludge Composting. USDA - Agricultural Research Service, ARS-NE-79, February, 1977.

7. Ely, J. F., and E. L. Spencer. The Composting Alternative: Waste Disposal in Remote Locations. Research Department, Appalachian Mountain Club, 1978. 28 pp.

8. Epstein, E., J. M. Taylor, and R. L. Chaney. Effects of Sewage Sludge Compost Applied to Soil on Some Soil Physical and Chemical Properties. Journal of Environmental Quality. 5(4): 422-426, 1976.

9. Epstein, E., and G. B. Willson. Composting Sewage Sludge. In Municipal Sludge Management, Proceedings of the National Conference of Municipal Sludge Management, Pittsburgh, PA. June, 1974.

10. Epstein, E., and G. B. Willson. Composting Raw Sludge. In Proceedings of the 1975 National Conference of Municipal Sludge Management and Disposal. Anaheim, CA. August, 1975.

11. Epstein, E., G. B. Willson, W. D. Burge, D. C. Mullen, and N. K. Enkiri. A Forced Aeration System for Composting Wastewater Sludge. Journal Water Pollution Control Federation, 48 (4): 688-694, 1976.

12. Ettlich, W. E., and A. E. Lewis. User Acceptance of Wastewater Sludge Compost. Environmental Protection Technology Series, EPA-600/2-77-096, August, 1977.

13. Fay, S. C., and R. E. Leonard. Composting Privy Wastes at Recreation Sites. Compost Science/Land Utilization, V. 20(1): Jan.-Feb.. 1979. pp 36-39.

14. Hornick, S. B., J. J. Murray, and R. L. Chaney. Overview on Utilization of Composted Municipal Sludges, In Proceedings of the National Conference on Municipal and Industrial Sludge Composting - Materials Handling. Information Transfer, Inc.. Silver Spring, Maryland, Nov. 14-16, 1980. pp. 15-22.

15. Leonard, R. E., and S. C. Fay. A Compost Bin for Handling Privy Wastes: Its Fabrication and Use. Forest Service Research Note: NE-254, 1978. 6 pp.

16. Leonard, R. E., and H. J. Plumley. Human Waste Disposal in Eastern Backcountry. Journal of Forestry, 77(5): 349-352, June, 1979.

17. Lombardo, Pio. Septage Composting. Compost Science/Land Utilization, 18(6): Nov.-Dec., 1977.

18. Lombardo, Pio. Rehoboth, Seekonk, Swansea, MA. Septage Composting Pilot Project - Final Report. 90 Canal Street, Boston, MA.. July, 1977. 16 pp.

19. Mosher, D., and R. K. Anderson. Composting Sewage Sludge by High-Rate Suction Aeration Techniques. EPA - Interim Report SW-614d. U.S. Environmental Protection Agency, Cincinnati, OH., 1977, 50 pp.

20. Parr, J. F., E. Epstein, and G. B. Willson. Composting Sewage Sludge for Land Application. Agriculture and Environment. 4: 123-137, 1978.

21. Patterson, J. C. Enrichment of Urban Soil with Composted Sludge and Leaf Mold-Constitution Gardens. Compost Science/Land Utilization. 16(3): May-June, 1975. pp. 18-21.

22. Patterson, J. C., and C. S. Rodgers. Static Pile Composting - A Waste Treatment Alternative. Parks. 4(1): April-May-June, 1979. pp. 16-19.

23. Patterson, J. C., and J. R. Short. Composting - An Attractive and Economical Way to Recycle Urban - Produced Organic Materials. In Proceedings of the 1st Conference on Scientific Research in The National Parks. G.P.O. Stock No. 024-005-00743-1, V. 11 - presented Nov., 1976, published 1979. pp. 1101-1105.

24. Patterson, J. C., J. R. Short, and E. Epstein. A solution to a Solid Waste Management Problem: Composting of Raw Sewage Collected from Sanitary Toilets Along the C&O Canal. Presented at the Northeast American Society of Agronomy. Burlington, VT., June 29, 1977.

25. Poincelot, R. D. The Biochemistry and Methodology of Composting. Conn. Agri. Experiment Station Bulletin 754, 1975.

26. Rand, M. C., et al., (ed). Standard Methods for the Examination of Water and Wastewater. 14th Edition, American Public Health Association. Washington, DC., 1976, 1193 pp.

27. Rennie, B. R., The Lebo Process for Composting Septic Tank Waste and Sewage Sludge. Rumsey and Co., Inc., Seattle, WA.. 1977. 35 pp.

28. Rennie, B. R. The Lebo and GroCo Methods of Composting. In Proceedings of the National Conference on Municipal and Industrial Sludge Composting - Materials Handling. Information Transfer, Inc., Silver Spring, MD.. Nov. 14-16, 1980. pp. 112-125.